IMPLEMENTATION OF VTI TRAFFIC SIMULATION MODEL ON DEC-10 SYSTEM AND ITS MODIFICATIONS FOR INDIAN TRAFFIC CONDITIONS

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By

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CERTIFICATE

Certified that the work on 'Implementation of VTI Traffic Simulation Model on DEC-10 System and its Modifications for Indian Traffic Conditions' by Pradeep Tiwari has been carried out under my supervision and that his work has not been submitted elsewhere for a degree.

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SYNOPSIS

A traffic simulation model describes the behaviour of individual vehicles as they traverse a given section of road. Of the various traffic simulation models of two lane highways developed so far, VTI model developed at National Road and Traffic Research Institute of Sweden is quite comprehensive. It also includes a probabilistic submodel for overtaking manoeuvres. The model uses structured programming technique and the programming language is SIMULA-67. It is proposed to implement VTI model on DEC 10 System. SIMULA compiler for this system differs from that of SIMULA-67 in a number of ways. This necessitates a lot of changes to be made in the documented programme of VTI model. About one third of the statements in the model are modified.

Indian traffic conditions are extremely heterogeneous involving large variations in vehicle types, their attributes and the flow pattern. This renders VTI model unanswerable to the Indian conditions. The study aims at modifying the model to incorporate the flow logics associated with mixed traffic without changing the basic structure of the model.

The traffic has been divided into seven categories of fast and slow moving vehicles. The values of various

attributes of the vehicles like desired speed, air-resistance, power-weight ratio, acceleration/retardation rates have been revised.

In mixed traffic flow, at times, two or more vehicles may be travelling at their free speeds in one lane width without any interaction. The interaction submodel is so modified that whenever it is necessary to calculate a reference to a vehicle travelling ahead, travelling behind or travelling alongside, test for interaction is resorted to. Various combinations of vehicles that interact in a lane are formulated.

VTI model considers 32 different overtaking situations and the gap acceptance relationships are tabulated for each. For considering a very large number of overtaking situations in case of mixed traffic flow, the model is so modified that the probability of accepting an overtaking for a gap size depends upon type of overtaking (flying or accelerative), roadwidth (paved or unpaved shoulders), category of overtaking vehicle, category of overtaken vehicle and category of oncoming vehicle. By grouping some of the categories it is possible to have 140 combinations when limitation is due to sight distance and 700 combinations when limitation is due oncoming vehicle. A computer programme

is also developed in SIMULA to generate various vehicular attributes. This generated data is given as input to the simulation process.

The modified model has enough flexibility for introducing other changes related to vehicular attributes and flow logics that may be thought desirable for different road traffic setups. The model can be applied for research, planning and design in Traffic Engineering in multiple ways.

1 INTRODUCTION

1.1 General

Most of the roads in the primary highway network of India have two lane wide pavements and carry two way movements. They generally have 7.0 meter wide pavement with unpaved shoulders on the sides. Since a large share of the highway traffic moves on two lane roads, study of traffic flow on these highways assumes pivotal importance. As compared to the western countries, Indian traffic structure poses added complicacies in terms of a highly heterogeneous mixture of vehicles, their attributes and the traffic stream logics. Composition of traffic is such that the vehicles generally do not remain in any specified lane. Slow moving vehicles mostly keep to the left while the faster ones move in the middle of the road. This further compounds the problem.

Traffic flow modelling aims at deriving theoretical and/or empirical relationships between the variables to depict the characteristics of traffic stream. There are three variables of particular interest namely speed, volume and density which together describe the quality of service. A traffic flow model can be used to evaluate capacity of the road at various levels of service and also for evaluating effectiveness of alternative remedial aids in terms of traffic

flow and traffic safely. A considerable amount of work has been carried out in this area in recent past. This involves both analytic and simulation models of traffic flow behaviour. These models are briefly reviewed in the following section.

1.2 Review of Traffic Flow Models

1.2.1 Analytical Models

An analytical model bases itself upon a set of equations describing the behaviour of vehicles along the road. Broadly speaking these models are of two types- microscopic and macroscopic (Martin and Voorhess, 1977). Microscopic models take up individual vehicles and study their behaviours and interaction with the traffic stream. Macroscopic models emphasise on modelling the character of entire traffic stream under steady state conditions. Problem formulation and solving the equations is key to the analytical models. When level of details in the data increases, formulation itself becomes difficult. Such is the case while dealing with the complex traffic flow process; hence a comprehensive analytical model may not be a viable proposition to tackle such problems.

1.2.2 Simulation Models

When a comprehensive analytical models cannot be conceptualized and formulated due to increased level of

complexities in terms of stochastic nature of the process and coherent system components and perhaps the presence of multiple alternatives and constraints, computer simulation of the process may be successfully adopted. A traffic simulation model describes the behaviour of the traffic stream by considering in detail the behaviours of individual vehicles as they traverse a specified section of road. The proximity of the simulation model to the real life depends upon the accuracy of the submodels, the way in which the submodels are linked together and the inclusion of all relevant submodels.

The first step in traffic simulation is to describe an input set of vehicles which when aggregated represent the total traffic stream to be simulated. Each individual vehicle in the set is identified and labelled according to its vehicle type, desired speed class, speed and power to weight ratio etc. The vehicles are input into the system at intervals specified by a highway distribution and advanced along the road in a manner governed by predetermined set of rules. Some rules are deterministic while others are stochastic in nature and can therefore result in one of the several responses. In recent years quite a few traffic simulation models have been developed for two lane highways. A few of them developed in last five years find a brief review here.

German (Brilon, 1974; Wiedmann, 1974) model conceptualizes an analytic description of traffic on two lane two way highway on the basis of a moving queue and service counter concept. The model establishes a relationship relating mean travel time, mean spot speed and limits of the overtaking rate to the traffic flow on a straight section. The stochastic inputs are desired speed, headway and overtaking characteristics. The oncoming traffic is represented as a distribution of gaps which are not affected by overtaking in the forward stream of traffic. The simulation is event based. Events are said to occur in catching up of a slower car and at the appearance of gap in the oncoming traffic flow. The inputs to the model are both deterministic and stochastic; the deterministic inputs are road, traffic and vehicles whereas stochastic inputs are desired speed, headway and overtaking characteristics.

In stock and May (1976) model, only one direction of traffic flow is dealt in microscopic detail whereas oncoming stream is modelled only as a distribution of gaps moving at uniform speed. The individual vehicles in the primary stream are assigned desired speeds from a Normal distribution and headways from either a Poisson or a Schul's distribution. The model defines one class of cars and six sub-classes of trucks. Only cars are allowed to overtake in accordance with an empirical gap acceptance distribution

and favourable traffic conditions. Car following distances depend upon speed and are Log Normally distributed. As another limitation speeds are independent of road geometry.

Marwah (1976) simulates mixed traffic (six different types of vehicles) on a level tangent section of a two lane two way road. The model has been used to study the interaction between vehicles under varying volume levels and compositions.

Akonteh's (1977) model is a simple model in that it relies on relatively small amount of empirical data. The model rests on a simple relationship involving driver behaviour, acceleration/deceleration, car following function and kinematics or force equations. Through this relationship Akonteh has attempted to model the acceleration of the vehicle at any time moment as a function of vehicle speed, the driver behaviour, and the position of the vehicle with reference to the road geometry and other vehicles. The desired speed is defined only for a level tangent road section and overtaking submodel is deterministic.

VTI (Gynnerstedt, 1977) model underway at National Road and Traffic Research Institute (VTI) is based on large scale data collection in connection with overtaking behaviour and desired speed distribution. The desired speed is related to road width, speed limit, horizontal curvature and gradient.

There are thirty two different types of overtaking manoeuvres considered. The roadway is divided into homogeneous sections called 'blocks'. Four categories of vehicles have been considered in the model. The scanning is event oriented. The model is being validated in stages and at present preliminary results have been obtained for free flowing traffic. The tedius part of the model is the large amount of field work required for the input data.

Kaesehagen (1978) model has the most striking feature of its excessive reliance on empirical speed and fuel consumption data under free flow traffic. It uses Schul's headway distribution and Normal distribution for the vehicle entry speeds. It assumes a constant minimum headway with correction for excess vehicle length. Acceleration speed curves are developed from the field data. The overtaking submodel is deterministic and the scanning is fixed time oriented. The model has not yet been validated.

MRI model was developed by St. John and Kobett(1978) at Midwest Research Institute (MRI) under the National Cooperative Highway Research Programme. The idea behind this study is to simulate traffic flow on two lane highway to determine the performance capabilities of vehicles and role that performance and size play in traffic instabilities,

accidents and loss of capacity. The entry time headways are based on Schul's distribution. The desired speed for each vehicle is selected from a truncated Normal distribution. The probabilities of accepting an overtaking opportunity are related to the speed of the leading vehicle and the passing opportunity distance.

Gravem (1979) suggests a simulation model for two lane highway network. Under development in Norway it is a microscopic discrete event traffic simulation model. It includes for road description the factors like vertical and horizontal alignment, road surface characteristics and cross section, traffic regulations, intersections, auxiliary lanes, sight distance etc. Each driver-vehicle unit is modelled in detail. Vehicles operating in the model are categorized into four classes-one for private cars and three for trucks. Their performances are described through the force equation, which includes motor forces and motion resisting forces. Actions carried out by the drivers are acceleration, deceleration, overtaking, car following, passing, driving into an auxiliary lane, waiting for suitable gap etc. The model can be used to evaluate existing or proposed design of a highway network and to assess the effects on traffic operations, safely, and fuel consumption when highway geometrics, traffic regulations, driver-vehicle characteristics, flow conditions etc. are changed.

1.3 Statement of the Problem

Of the various traffic simulation models that exist to date VTI model stands out as most advanced and comprehensive. This model uses Jackson Structured Programming (Jackson, 1975), JSP, technique in systems and programming work. The programming language used is SIMULA-67 which has exceptional qualities for simulation as well as permits a lucid organization of the programme text and well-structural data. Some concepts of this language are given in Appendix I.

The model has already been calibrated for free flow conditions. SIMULA-67 language compilers are not available in India. DEC-10/20 SIMULA compilers as available in a few installations in this country differ from SIMULA-67 in a number of respects. The computer programme as documented by VTI thus needs a lot of alterations while implementing on the DEC System.

VTI model as it stands originally is framed for Swedish traffic conditions which are far too homogeneous and streamlined than the ones existing in India. Indian traffic conditions are extremely heterogeneous involving large variations in vehicle types, their attributes and the flow pattern. This renders VTI model unanswerable to the Indian conditions. The study also aims at modifying the model to incorporate the flow logics associated with mixed traffic

flow thereby studying the traffic flow behaviour under varying road and traffic conditions. Moreover the study intends to create a platform for development of a comprehensive traffic simulation model for Indian conditions. In short the objectives of the study are:

(i) To understand SIMULA-67 programme of the VTI model.

(ii) To implement the model on DEC 1090 System after making the necessary changes in the programme.

(iii) To modify the computer programme to make the model adaptable to the mixed traffic conditions without significantly deviating from the basic structure of the model.

1.4 Limitations of the Study

The subject matter in question is very comprehensive. Moreover there are limitations of time and availability of realistic data. The study is therefore restricted to the following:

(i) The model is modified to take care of seven categories of vehicles namely, truck/bus, car, horse-driven-cart, bullock-cart, scooter, cycle-rickshaw, bicycle, their attributes and the traffic stream logics applicable to them. Field data are needed for estimating the vehicular attributes. Various submodels associated with flow logics need also be calibrated with realistic field data.

(ii) It provides for only two-lane roads which are of two types (1) with hard shoulders, (2) without hard shoulders. No further classification of shoulders such as dry or wet etc. have been considered.

(iii) Sight distance limitations have been included.

(iv) The output from the model remains unvalidated due to lack of realistic data whose collection falls outside the scope and time of the project.

2 VTI MODEL DESCRIPTION

2.1 Introduction

VTI traffic simulation model is part of a comprehensive, long-term Research and Development Project being performed at the National Swedish Road and Traffic Institute (VTI-Vag-och trafikinstitut). It has progressed since 1969 under the sponsorship of National Swedish Road Board. The purpose of this project is to determine the effect of road and traffic engineering schemes on traffic in order to establish traffic quality and road user cost in the rural road network. This has led to the development of the traffic simulation model which describes the dynamic sequence of vehicular traffic over defined stretches of road for given traffic volume and traffic composition.

The model assumes that each vehicle has a basic desired speed at which it would like to travel. However, it is usually prevented from doing so by one or both of the following factors:

(i) The road geometry and/or speed limit;

(ii) The presence of other vehicles on the road i.e. when vehicular interaction is there.

In what follows is a description of the VTI model under these two heads plus a brief account of the input

data required to run the model and about the various results and analyses that can be obtained from the model. The description is obtained from the VTI Reports No. 43 (VTI, 1977) and No. 143 (VTI, 1979).

2.2 Model for Free Moving Vehicles

Following are the factors which prevent a vehicle from travelling at its basic desired speed at which it would like to travel under ideal conditions:

(i) Road width (including the existance or otherwise of hard shoulders);

(ii) Bends (horizontal curvature);

(iii) Speed limit ;

(iv) Hills (gradient).

For each vehicle a speed is determined based on the first three factors above and the effect of gradient is then superimposed to obtain the actual speed. Also, each vehicle input into the simulation is assigned a speed class. There are total of 25 classes each representing a 4- percentile of the basic desired speed distribution. To arrive at desired speed distribution for straight level roads spot speeds were taken at three points several kilometers apart. To identify those vehicles which were travelling unimpeded the vehicles were photographed as they passed each point. For vehicles which were unimpeded

at two or three points along the road section the highest speed was taken as the desired speed; for those unimpeded only at one point the speed at that point was taken as the desired speed. Thus a V_0-distribution was obtained. The fastest speed distribution was related to a road width greater than 12 meters (normally roads having 3.5 meter lane and 3 meter shoulders are fairely common in Sweden).

To incorporate the effects of roadwidth, horizontal curvature, speed limit and gradient V_0 was adjusted by taking each one of them cumulatively as shown in Fig.2.1.

To obtain the effects of these factors suitable submodels were developed and they are described in VTI Report No. 43 (VTI, 1977). In order to simplify the calculation of the speed relationships, various transformations were used such that Q (the speed difference from V_0 to V_3) was the same for all speeds, i.e. the curves were transformed into a family of curves in which V^q was plotted rather than V (q being the calibration constant).

Four types of vehicle classes are assumed depending on the number of axles:

(i) Private cars;

(ii) Trucks with 2 or 3 axles;

(iii) Trucks and trailers with 3 or 4 axles;

(iv) Trucks and trailers with more than 4 axles;

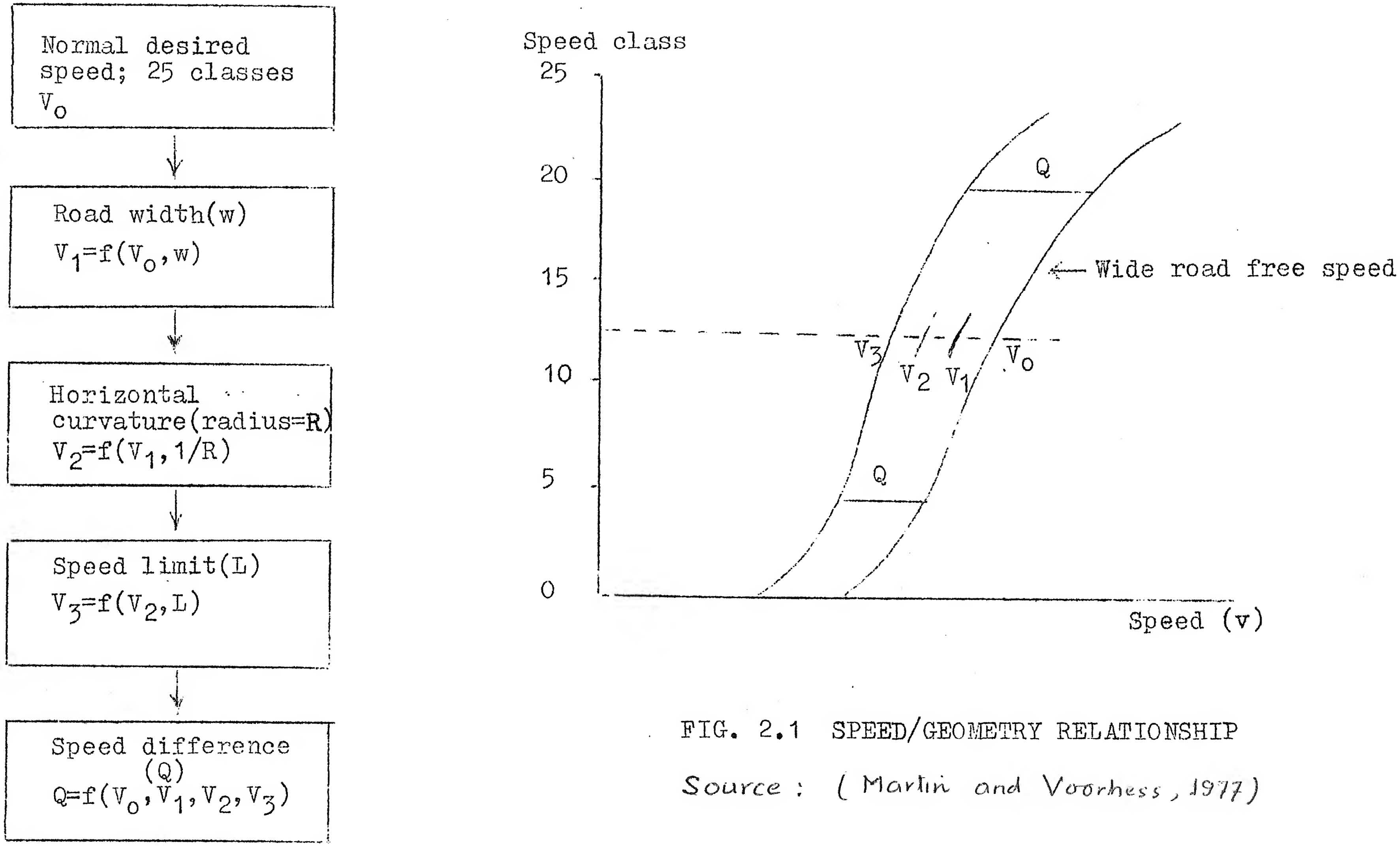

FIG. 2.1 SPEED/GEOMETRY RELATIONSHIP

Source : (Martin and Voorhess , 1977)

and each of these vehicle types is assigned a power to weight ratio. These ratios are derived from observations on gradient using the following expression:

$$p = \frac{V_o^2 - V_1^2}{2S} + \frac{gh}{S} + \frac{C_r(V_o+V_1)}{2} + f(C_A, V_o, V_1)$$

where V_o = speed at the start of the section

V_1 = speed at the end of the section

S = section length

h = vertical height climbed

C_r = constant of rolling friction

C_A = constant of air friction

g = acceleration due to gravity

The p valves are used to modify V_3 distribution in order to incorporate the speed reduction on hills and also to govern the rate of acceleration both on hills and on the flat.

In the model the road is split up into what are called 'homogeneous sections', also termed as 'blocks'. These sections have a constant roadwidth, speed limit, horizontal curvature and gradient throughout their length. A change in any one of them marks the beginning of a new block or the block limit. Since V_3 (mentioned earlier) depends upon road geometry a discontinuity in the speed profile may be expected at each block limit. To get around this problem the concept of what is called 'Influence Block'

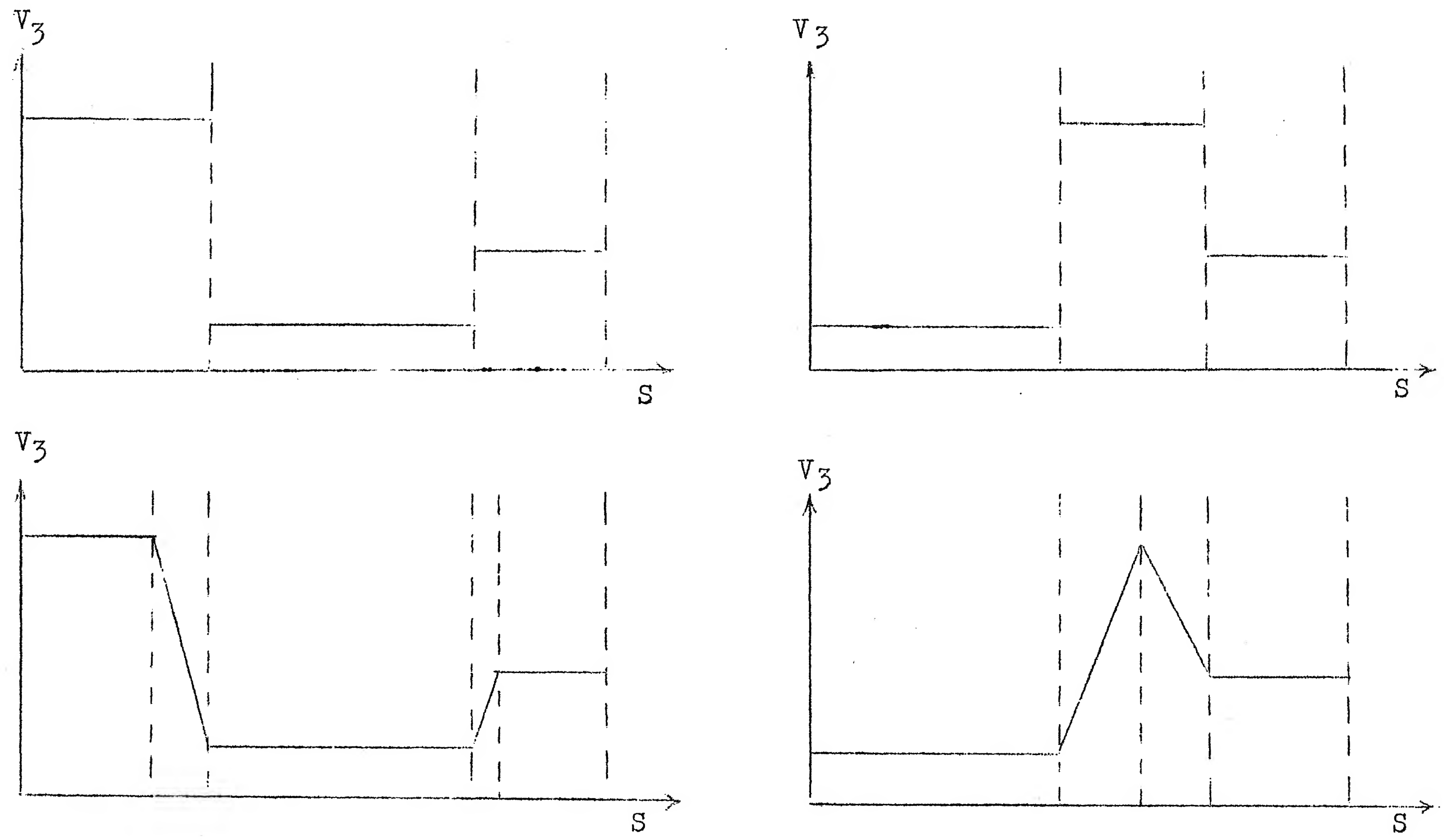

FIG. 2.2 CONTINUITY OF SPEED/ACCELERATION PROFILE-INFLUENCE BLOCKS

Source : (Gynnerstedt , 1977)

is introduced. Creation of these influence blocks ensures a gradual decrease or increase in speed or acceleration of the vehicle at the point of discontinuity. Fig. 2.2 elucidates the point.

2.3 Model for Interacting Vehicles

A vehicle is said to be interacting if it is either constrained by another (i.e. following) or is overtaken or is being overtaken by another vehicle. There are thus three modes of overtaking considered.

(i) Flying or Direct Overtaking: When the vehicle overtakes at the same speed at which it was travelling and the vehicle in front does not have to shift to the other lane.

(ii) Accelerative Overtaking: When the vehicle travelling behind slows down and follows the vehicle in front for some time before it gets an opportunity to accelerate and overtake.

(iii) Passing: This is similar to the first type except that here direct overtaking takes place with a lane change by the vehicle in front to create space for the passage of the overtaking vehicle.

An event is said to have occured at a point of time whenever a vehicle changes its state of motion. Since speed of a single free moving vehicle is determined by the road conditions only, the only event for such a

vehicle is passage of a block limit. However, for interacting vehicles there are additional event types which occur whenever status of a vehicle changes. These include: a decision point for flying/accelerative overtaking or passing; a point of overtaking; the point where overtaking finishes; and a block limit. In the model 32 different types of overtaking manoeuvres have been considered. They are the outcome of the permulations of (1) flying/accelerative overtaking type, (2) oncoming vehicle/sight distance restriction, (3) 4- types of overtaken vehicles and (4) road width- with and without hard shoulders. Using the test vehicle as overtaken experiments are performed to arrive at the gap length accepted or rejected for overtaking. This data is then converted into probability of a given gap being accepted. Thus in the simulation model whenever an overtaking opportunity presents itself, it is categorized into one of these 32 types and probability of gap being accepted is decided by Monte Carlo Technique.

2.3.1 Decision Point for Flying Overtaking

Suppose a free moving vehicle p_i (Fig. 2.3) is catching up with a slower vehicle p_j and has to decide whether to flying-overtake p_j or not. In this decision process it is assumed that if p_i rejects the overtaking opportunity then it must be able to decelerate at a fixed

rate R to reach a fixed time headway T away from p_j, when p_i has attained the speed of p_j ($R=3$m/sec/sec and $T=1$ sec).

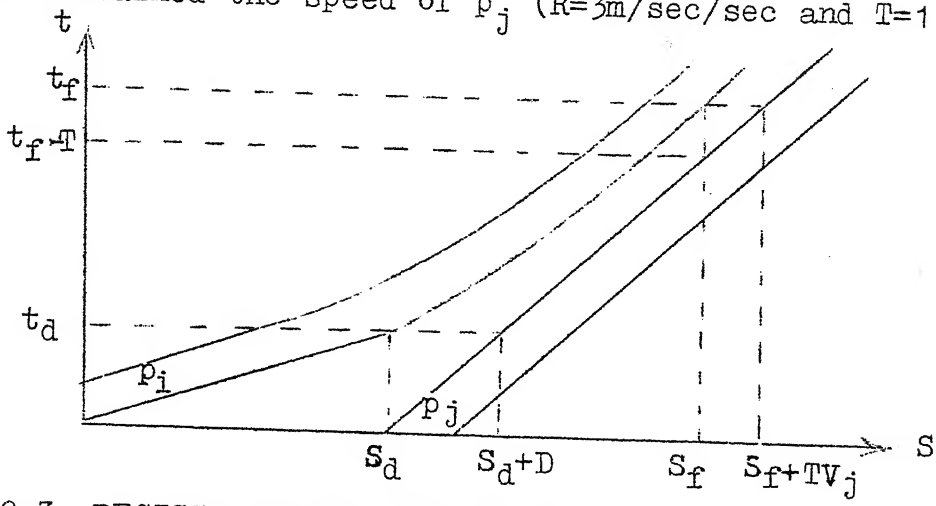

FIG. 2.3 DECISION POINT FOR FLYING OVERTAKING

Let (S_d, t_d) be the decision point for flying-overtaking and (S_f, t_f) be the point when p_i has decelerated to the speed V_j of p_j. Let D be the distance headway at time t_d then

$$D + V_j\,(t_f - t_d) = (S_f + TV_j) - S_d$$
$$V_i - V_j = R(t_f - t_d)$$
$$1/2V_i^2 - 1/2V_j^2 = R(S_f - S_d)$$

Therefore $$D = TV_j + (V_i - V_j)^2/2R$$

The point at which the decision on flying overtaking is made this distance D is the maximum. There are other occasions when a decision must be made at a shorter notice. For instance, if p_i is at the point of overtaking another vehicle p_k, then p_i may make an immediate decision on flying-overtaking the next vehicle ahead if the

new headway is less than or equal to D. The rejection of flying-overtake p_j by p_i entails automatic constraining of p_i by p_j and, in other words, p_i starts following p_j. p_i may then have to make a subsequent decision of accelerative-overtaking p_j.

2.3.2 Decision Point for Accelerative Overtaking

While p_i is under constraint by p_j the decision for accelerative-overtaking coincides with the following two situations:

(i) A block limit where an extra lane (i.e. a crawling lane or wide hard shoulders) begins.

(ii) A point of maximum sight distance.

In the second case if the sight distance is restricted by an oncoming platoon and the opportunity for overtaking was rejected under that situation then a new decision is made after the passage of the last vehicle of the platoon. If still the overtaking opportunity is not accepted further decision points as cited earlier are generated until p_i does decide to overtake p_j.

2.3.4 The Overtaking Decision Process

Suppose a decision is to be made by p_i as to whether or not to overtake p_j. Let block (i) and block(j) be the road blocks currently occupied by p_i and p_j. Then the overtaking is rejected under any of the following situations:

(R_1) p_i is itself being overtaken

(R_2) p_i cannot attain enough power to overtake p_j(this condition is applicable only in case of accelerative overtaking)

(R_3) There exists no-overtaking zone in block (i)

(R_4) There exists a solid white line in block (i) and there is no extra lane in block (j). If there is an extra lane then 'Passing'manoeuvre takes place depending upon the probability of p_j moving over to the extra lane and creating space for overtaking (passing). This generates the following acceptance opportunity, namely

(A_1) There exists an extra lane in block (j) and p_j moves into it.

The model uses Monte Carlo Techniques to arrive at the probabilities under all such cases.

2.3.5 Prediction of Events

The model relies on provision of an up-to-date list consisting of details, for each vehicle, of the event currently predicted to take place next, shortly called 'event notice'. The simulation progresses by selecting the next predicted event in this list and examining the consequences thereof.

2.4 Model Input

Model inputs are divided into two parts:

(i) Road Data: The model requires that every road to be simulated be described (in each direction) as a series of homogeneous blocks of constant road geometry and traffic regulations. The parameters that describe a road block in each direction are: (1) Distance coordinate, (2) Width, (3) Radius of curvature, (4) Slope, (5) Speed limit, (6) Overtaking restriction code (7) Hard shoulder code (8) Distance coordinate of sight-distance maximum/minimum, (9) Sight distance. Here 5, 6 and 7 come under traffic regulations.

(ii) Vehicle Parameters: The parameters required by the model for each vehicle are (1) Identify number, (2) Vehicle class, (3) Speed class, (4) Power to weight ratio, (5) Direction, (6) Initial and final block numbers, (7) Initial time coordinate and speed. Here 2, 3 and 4 describe the vehicle characteristics and 6 and 7 describe the boundary conditions.

2.5 Model Output

The information that is obtainable as the model output can be given under the following heads:

(i) Summary of results: At the conclusion of each simulation run following summary of result is printed:

Total number of vehicles simulated; total vehicle-kilometers simulated; mean journey time along the whole

simulated road; mean journey speed along the whole simulated road; total number of overtaking vehicles, total number of vehicles overtaken.

(ii) File of Simulated Vehicle Movements: This gives a record of each simulated vehicle in each direction giving identity number; vehicle class; time coordinate ; spot speed ; journey speeds; time headways, identifier of vehicles immediately in front/behind of the vehicle; number of overtakings by the vehicle and the number of time the vehicle was overtaken.

(iii) File of Events: Record of each event in the simulation run is output in terms of the time of the event; the primary vehicle in the event; the event type and a fund of information giving the state of vehicles on the road at the time of occurance of the event.

The computer programme as documented by VTI (1979), however, prints only the file of events (No. iii).

2.6 Critical Assessment of the Model

Validation results of VTI Model show a close fit between simulated speed distributions and observed data but the model still overpredicts the number of overtakings. Work is being carried out to obtain better aggrement between simulated and observed number of catch-ups and passings and queue lengths. The model is also being modified for lane

width under 7.0 meters and for poor horizontal alignments. The U.K. Department of Transport is in the process of adopting VTI model for use in the evaluation of minor road improvements in England. It is currently capable of handling most of the variables, e.g. roadwidth, shoulder type, horizontal alignment, speed limit and vertical alignment with the exception of surface type and condition.

One of the principal strengths of VTI model for policy analysis purpose lies in its overtaking submodel which simulates passing behaviour on a probabilitic basis. The overtaking submodel uses actual overtaking observations for model calibration, taking into account the overtaking situation (e.g. whether flying or accelerative overtaking, sight distance restriction due to geometry or an oncoming vehicle etc.). Transferring the model to any other conditions may call for recalibration of overtaking submodel since the drivers of two countries may behave quite differently.

Although probabilistic approach modelling overtaking is in principle preferrable to deterministic approach some aspects of VTI overtaking submodel have been questioned. The ones raised by Mr. Kaesehagen (Watanatada, 1978) are:

(i) In the gap acceptance functions for flying overtaking no account is taken of the speed differential between the overtaking vehicle and the vehicle being overtaken.

(ii) In the absence of auxiliary lanes and hard shoulders the model assumes too few opportunities for drivers to make accelerative overtaking dicisions. In the model overtaking opportunities occur when the overtaking vehicle reaches a point of maximum sight distance.

(iii) It is not clear whether the size of gap for re-entry of the overtaking vehicle is considered in overtaking decision.

(iv) Overtaking probabilities are insensitive to the type and performance characteristic of the overtaking vehicle.

(v) An overtaking is assumed to finish after a fixed time interval (value of the time interval depending on the type of the overtaking vehicle) irrespective of the speed differential or whether the overtaking was flying or accelerative.

2.7 Implementation of VTI Model Programme on DEC System

The computer programme of VTI model is written in SIMULA-67 language. This special purpose simulation language has still not been widely used in this country and hardly any expertise is available for it. The computer installations in the country do not have the SIMULA-67 compilers. DEC 1090 System installed at Indian Institute of Technology Kanpur only a year back has DEC 10/20 System SIMULA compiler.

This study is the first major simulation project in this country that has used SIMULA. After learning the basic concepts of the language considerable time and effort was required in understanding VTI model computer programme. There were a number of constraints like lack of guidance in programming and scantily available literature on SIMULA language. Mr. Gynnerstedt, author of the VTI model was kind enough to send some relevant literature on SIMULA and a listing of specimen model input and output data.

DEC 1090 System SIMULA compiler differs from SIMULA-67 one in some respects. This necessitated a lot of changes to be made in the documented programme of VTI model. About one third of the statements in the model were modified. After compiling the programme a number of bugs were removed during execution. Input output data listing obtained from VTI was immensely useful while debugging. The understanding and implementation of the programme took more than six months. There was a close coordination with the study team of VTI. Besides postal communications with VTI there were two meetings between Dr. B. R. Marwah and Mr. Gynnerstedt, one in August 1978 in Sweden and the other in Delhi during April 1979. These contributed a lot in understanding some of the details of the model.

3 MODIFICATIONS OF VTI MODEL FOR INDIAN TRAFFIC CONDITIONS

3.1 Complexities of Mixed Traffic Flow

Traffic on Indian highways is heterogeneous in character. It includes both fast and slow moving vehicles among which there are wide variations in speeds and dimensions. Fast moving vehicles such as cars and trucks interact with a number of slow moving vehicles like horse-driven-carts, bullock-carts, bicycles and cycle-rickshaws which form a major share of the total vehicular traffic. Two wheeled motor vehicles like scooters/motor cycles also affect the flow of other vehicles. This heterogeneous type of traffic gives rise to a number of problems in developing a traffic simulation model. The variation in dimension of different categories of vehicles significantly affectsthe traffic flow logic i.e. overtaking and passing in the simulation process. Wide vehicles such as trucks, cars, bullock-carts etc. occupy almost full lane while moving at their free speeds whereas two-wheelers like scooters and bicycles occupy very little width and hence two or more of them can travel abreast in one lane. Scooter needs more clear width than bicycle because of its higher speed. Similarly truck and car generally require more clear width of road than horse-driven-cart or bullock cart.

Three wheelers like auto-rickshaw and cycle-rickshaw require clear width for movement depending upon their own characteristics.

It is extremely difficult to express the speed flow relationships for the complex mixed traffic composition unless the interactions between the vehicles are studied in detail by a realistic simulation model. Most of the national highways in this country are only two lane wide with unpaved shoulders on both the sides. Traffic volume is quite heavy and thus the vehicles cannot maintain any lane discipline. The faster vehicles generally keep to the middle of the road whereas slower vehicles generally move on the left. In the mixed traffic conditions the faster vehicles come across a number of desired overtakings or passings. The probability that a vehicle can overtake at any instant at a particular point depends upon the characteristics of the vehicles moving along or opposite to it. The simulation model should thus have overtaking/passing logics which represent behaviour of the different categories of vehicles.

When a scooter desires to overtake a cycle-rickshaw/bicycle then another scooter coming from opposite direction and travelling within the overtaking zone may still not restrain the overtaking as the scooter and a cycle-rickshaw/bicycle may travel parallel to other at

their free speeds on a two lane highway. But a car desiring to overtake a bullock-cart is forced to move on to the wrong lane during overtaking and another vehicle like car/truck/horse-driven-cart/bullock-cart coming from opposite direction may restrain the overtaking.

3.2 Limitations of VTI Model

VTI traffic simulation model though most advanced amongst the various simulation models, cannot be directly applied to the Indian traffic conditions because of some of the following limitations:-

(i) The model considers only four classes of vehicles namely:

(1) Private cars;

(2) Trucks with 2 or 3 axles;

(3) Trucks and trailers with 3 or 4 axles;

(4) Trucks and trailers with more than 4 axles.

These four classes of vehicles though vary to some extent with regard to speeds, lengths and widths but all of them use full traffic lane for movement. The formulation of the model is thus comparatively simple as there can be only one vehicle at a point on a lane. Overtaking vehicle moves to the wrong lane and overtaking operation may be restrained by any class of oncoming vehicle. This type of formulation is not a true representation of the heterogeneous traffic. Overtaking and passing logics

are the most important and crucial parts of a traffic simulation model as they represent the interactions between the vehicles. It becomes thus essential to suitably modify these logics in the VTI model.

(ii) The vehicular characteristics like speed, power-weight ratio, acceleration/deceleration rates etc. of the motor vehicles like cars and trucks are significantly different in India from those in Sweden or other developed countries. These attributes decide some of the decision parameters like minimum headway during overtaking, minimum headway during free flow, trunklength, taillength etc. These vehicular characteristics can be suitably modified using actual field data. Compared to item No.1 above this will not result in any major change in the flow logic except changing some of the model inputs.

The above discussion indicates that major changes in VTI model are needed to make the model adaptable to the mixed traffic conditions and these changes are discussed in the following sections.

3.3 Modifications of Vehicular Attributes

The basic objective of the study is to make the necessary changes in VTI model to make it applicable to the heterogeneous traffic conditions without significantly deviating from the basic structure of the simulation model.

The traffic has been divided into the following seven categories, namely, (1) truck, (2) car, (3) horse-driven-cart, (4) bullock-cart, (5) scooter, (6) cycle-rickshaw and (7) bicycle. These seven categories represent the wide variations in the speeds and dimensional characteristics of the vehicles. It may be desirable to include a few more categories of vehicles like auto-rickshaw, mini-bus etc. The modified structure of the model is such that any other category of vehicles can be easily incorporated once the vehicular characteristics are well defined. In the programme the equipage is represented as an object from the CLASS VEH. The object has a number of attributes as given in Appendix II. An additional attribute of the object named CAT which defines the category of the object (from the CLASS VEH) has been included in the programme structure to account for different categories of vehicles. The values of the various attributes of the vehicles have been revised based on results of some of the other studies. These values may be suitably modified when the detailed field data are available. Some of the modified values of the different attributes are as follows:

3.3.1 Speed Class

Every vehicle input into the simulation process is assigned a speed class. VTI model divides the basic desired speeds of all the vehicles into 25-classes. Each of 25

classes represent a 4 percentile of the basic desired speed distribution. The basic desired speed varies from 18.2 meters per second (for speed class 1) to 37.5 meters/sec. (for speed class 25). These limits do not hold good for the mixed traffic conditions as the slow moving vehicle like bullock-cart moves at a speed around 2.0 meter/sec. The basic desired speeds of the various speed classes as modified are listed in Table 3.1. This distribution of basic desired speed covers the entire range of the mixed traffic.

TABLE 3.1: BASIC DESIRED SPEEDS OF VARIOUS SPEED CLASSES

Speed class	Speed range (meter/sec.)	Speed class	Speed range (meter/sec.)
1	1.0- 2.0	13	18.5-20.0
2	2.0- 3.5	14	20.0-21.5
3	3.5- 5.0	15	21.5-23.0
4	5.0- 6.5	16	23.0-24.5
5	6.5- 8.0	17	24.5-26.0
6	8.0- 9.5	18	26.0-27.5
7	9.5-11.0	19	27.5-29.0
8	11.0-12.5	20	29.0-30.5
9	12.5-14.0	21	30.5-31.0
10	14.0-15.5	22	31.0-32.5
11	15.5-17.0	23	32.5-34.0
12	17.0-18.5	24	34.0-35.5
		25	35.5-37.0

3.3.2 Air-Resistances for Different Categories of Vehicles

VTI model uses separate values of air-resistances for each of the four types of vehicles. In this study the air-resistances for all the seven categories of vehicles were incorporated and they are given in Table 3.2.

TABLE 3.2 AIR-RESISTANCES FOR DIFFERENT CATEGORIES OF VEHICLES

Vehicle Category	Air-resistance
Truck	C2(1) = 0.000153
Car	C2(2) = 0.000281
Horse-driven-cart	C2(3) = 0.000050
Bullock-cart	C2(4) = 0.000050
Scooter	C2(5) = 0.000010
Cycle-rickshaw	C2(6) = 0.000030
Bicycle	C2(7) = 0.000010

These air-resistance values may be modified when the field data are available.

3.3.3 Power-Weight Ratio

As the name implies it is the ratio of the power (traction power) to the weight of the vehicle. This parameter figures while making an overtaking decision on

level as also on slope in that the overtaking vehicle should have enough power to weight ratio to be able to overtake the vehicle ahead or surmount a given slope. For mixed traffic flow, Table 3.3 provides the values of this ratio for different categories of vehicles. These may have to be modified when accurate data become available.

TABLE 3.3 POWER-WEIGHT RATIO FOR DIFFERENT CATEGORIES OF VEHICLES

Category of vehicles	Power-weight ratio
Truck	5.0
Car	12.0
Horse-driven-cart	3.0
Bullock cart	2.0
Scooter	5.0
Cycle Rickshaw	2.0
Bicycle	2.0

3.3.4 Retardation for Different Categories of Vehicles

When a vehicle cannot accept a given overtaking opportunity it slows down to the speed of the vehicle ahead. VTI model defines headlength as the distance(D) required to slow down with a given retardation (deacc) to the speed of the vehicle ahead. It is given by:

$$D = TV_j + (V_i - V_j)^2 / 2R$$

where

V_i - speed of the faster vehicle which is trying to catch up with a slower vehicle

V_j - speed of the slower vehicle

R - constant rate of retardation

T - fixed time headway

The retardation rate is taken to be 3.0m/sec.^{2} for all types of vehicles. The different categories of vehicles as considered in the study cannot have a constant retardation rate as this will depend upon desired speed, power-weight ratio etc. The retardation rates for different categories of vehicles as incorporated in the model are given in Table 3.4.

TABLE 3.4 RETARDATION RATES FOR DIFFERENT CATEGORIES OF VEHICLES

Vehicle category	Retardation (Deacc),M/sec^2
Truck, car	3.0
Scooter	2.0
Horse-driven-cart	0.2
Bullock-cart	0.2
Cycle-rickshaw	0.2
Cycle	0.2

The values of the various attributes were adopted based on the very limited available information, however, they appear to represent the characteristics of different categories of vehicles. These values along with those of a few other attributes may be suitably changed once detailed data are available.

3.4 Modifications of the Simulation Process

VTI model consists of two parts: (1) Free flow Model- which gives the speed of free moving vehicle along the road, (2) Interaction Model- which determines the interactions between the individual vehicles in the traffic stream.

3.4.1 Free Flow Model

In VTI model each vehicle is alloted a speed class in the desired speed distribution (divided into 25 classes). The factors that prevent a free moving vehicle from travelling at its basic desired speed are: roadwidth, speed limit, horizontal curvature and longitudinal gradients. The road section is divided into homogeneous blocks with regard to roadwidth, speed limit, horizontal and vertical curvatures and overtaking restrictions. The desired speed for a vehicle in a particular road block is designated as the vehicle's 'block speed'. Each vehicle is also allotted a power-weight ratio or p-value as well as air and rolling resistances, which decide its ability to reach or maintain

k speed on a particular slope. The free speed over the entire length of the road section is termined.

In case of mixed traffic flow it is thought able to have a separate distribution for each ry of vehicle. Using these distributions the desired speed for each vehicle is generated. ing upon the category of vehicle and its basic d speed it is also assigned a speed class. The speed profile of the vehicle over the entire length road section is then determined using the cteristics of different homogeneous road blocks.

Interaction Model

A vehicle interacts when it is either constrained other vehicle or a group of vehicles (called platoon) is overtaking/passing another vehicle or a group of les. Interaction between the vehicles does not permit to move at their free speed over the road section. action model is the most important part of the traffic tion process in that, it affects the entire behaviour traffic stream. The details of the interaction are available in (VTI, 1977) and (VTI, 1979).

VTI model divides the road width into the following tracks/lanes for each direction of travel.

(a) Track No. 2 : the right lane of travel

(b) Track No. 1 : the wrong lane of travel. (An overtaking vehicle occupies this track during lane-change in overtaking operation).

(c) Track No. 3 : hard side shoulders or climbing lanes which may be utilized by a vehicle to permit a passing operation. This track may not be present over entire length of the section like presence of unpaved shoulders.

In case of left hand drive, the classification of Tracks is as shown in Fig.3.1.

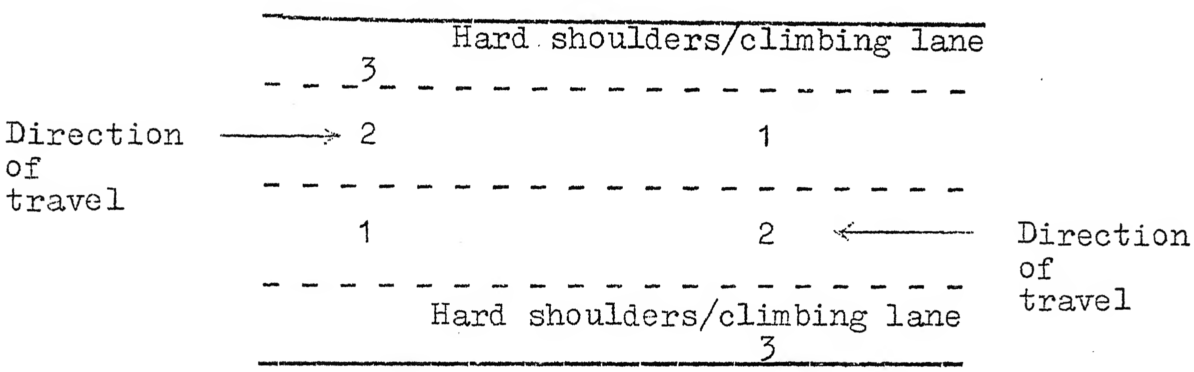

FIG. 3.1 CLASSIFICATION OF TRACKS IN THE MODEL

The vehicle interacts with another vehicle of the traffic stream moving in the same or opposite direction when they are quite close to each other in the same track. Each vehicle in the model is allotted a headlength and a tail-length. Headlength (called trunklength in the programme) is the distance required to slow down with a given

retardation to the speed of preceding vehicle. The taillength indicates the minimum spacing between the vehicles moving in a queue. When a fast moving vehicle catches up with a slow moving vehicle it may overtake/ pass or follow depending upon the spacing with the preceding vehicle and also on the overtaking mode of the succeeding vehicle.

Interaction model for the mixed traffic flow is quite complex to formulate due to large variations in the attributes of different categories of vehicles, which results in various types of interactions between the fast and slow moving vehicles. Most of our two-lane highways have 7.0 meter wide pavements with unpaved shoulders on the sides. The composition of the traffic is such that the vehicles generally do not remain in any specified lane. Slow moving vehicles like horse-driven-carts, bullock-carts, cycle-rickshaws and bicycles mostly keep to the left whereas faster vehicles like trucks/buses, cars move in the middle of the road. This results in a number of complexities as the vehicles do not occupy any particular lane. The width of the road occupied by a vehicle depends on the attributes of the vehicle. VTI model decides about the overtaking, passing or following mode when a vehicle is close to another vehicle in the same track. In mixed traffic flow, at times, two or more vehicles may be travelling at

their free speeds in one lane width without any interaction, like scooter and a bicycle/cycle-rickshaw in one lane. There can be many combinations. VTI model determines the operating mode for a vehicle by referring to the vehicle travelling behind and/or vehicle travelling ahead of it. This does not hold true for the mixed traffic flow. For example, a bicycle is travelling ahead of scooter and there is a bullock-cart ahead of the bicycle. Now for the scooter there is no interaction with the bicycle as both of them may travel at free speeds in the same lane but the scooter may interact with the bullock-cart as both of them can not remain abreast in one lane. Bullock-cart may restrain the overtaking operation if some wide vehicle like car, truck or bullock-cart is coming from opposite direction. The example brings about that for determining the operation mode of a vehicle one is not interested in the immediately close vehicles ahead or behind it but in that vehicle which is likely to interact. The interaction between the vehicles travelling in the same lane thus depends upon their categories. If this kind of test for interaction is incorporated then a faster vehicle may pass a slower vehicle without the later moving on to the side lane.

Procedures for Calculating Reference to Equipage Objects: VTI model is so modified that whenever it is necessary to calculate a reference to a vehicle travelling behind (VEHBEHITRK(X))

or travelling ahead (VEHFORWITRK(X)) or travelling alongside (VEHLITRK), test for interaction is resorted to for track No. 1 and 2. However, for track No.3, i.e. hard shoulders, the interaction is with the vehicle immediately behind or ahead and for this track the VTI procedure itself is adopted.

The operation of the procedure VEHFORWITRK(X) given in Fig. 3.2 is as follows:

(i) This procedure calculates a reference to the preceding (travelling ahead) vehicle in lane X. The parallel psuedo equipage object of object class is referred to calculate a reference to the preceding pseudo equipage object. For track 1 and 2 (X=1 and 2), procedure FRONTOFITRACK(X) is called and for track 3(X=3), procedure FRONT3OFITRACK(X) is called).

(ii) In procedure FRONTOFITRACK(X) Fig. 3.2b, the category of the current vehicle (S_3) and its road coordinate (S_1) are first determined. Now, starting with the last pseudo equipage object the coordinates of the current equipage (S_1) are compared with those of pseudo objects at clock time TIME till the pseudo object is ahead of the current vehicle. Category of this pseudo object (S_4) is checked to find if there is any interaction with that of the current vehicle(S_3). In case of no interaction the preceding pseudo object is

checked for interaction. This procedure is respeated till either there is a pseudo object having interaction with the current vehicle or there is no other pseudo object in track X. The vehicles interact for the combinations of the vehicles given in Table 3.5.

For track 3, the procedure FRONT3OFITRACK(X), given in Fig. 3.2 c, does not test for the interactions and reference is calculated for the preceding equipage.

TABLE 3.5 COMBINATIONS OF DIFFERENT CATEGORIES OF VEHICLES WHICH INTERACT IN THE SAME TRACK

Category of the current vehicle (S_3)	Category of pseudo equipage(S_4) which interacts with the current vehicle
Truck, car	All the seven categories
Horse-driven-cart, bullock-cart	Truck, car, horse-driven-cart bullock-cart, scooter and cycle-rickshaw
Scooter,cycle-rickshaw	Truck, car, horse-driven-cart, and bullock-cart
Bicycle	Truck, car

The operations of the procedures VEHBEHITRK(X), for calculating reference to vehicle travelling behind, and VEHLITRK(X), for calculating reference to vehicle travelling alongside, is like that of VEHFORWITRK(X) disdussed above. They are explained in Fig. 3.3 and 3.4 respectively.

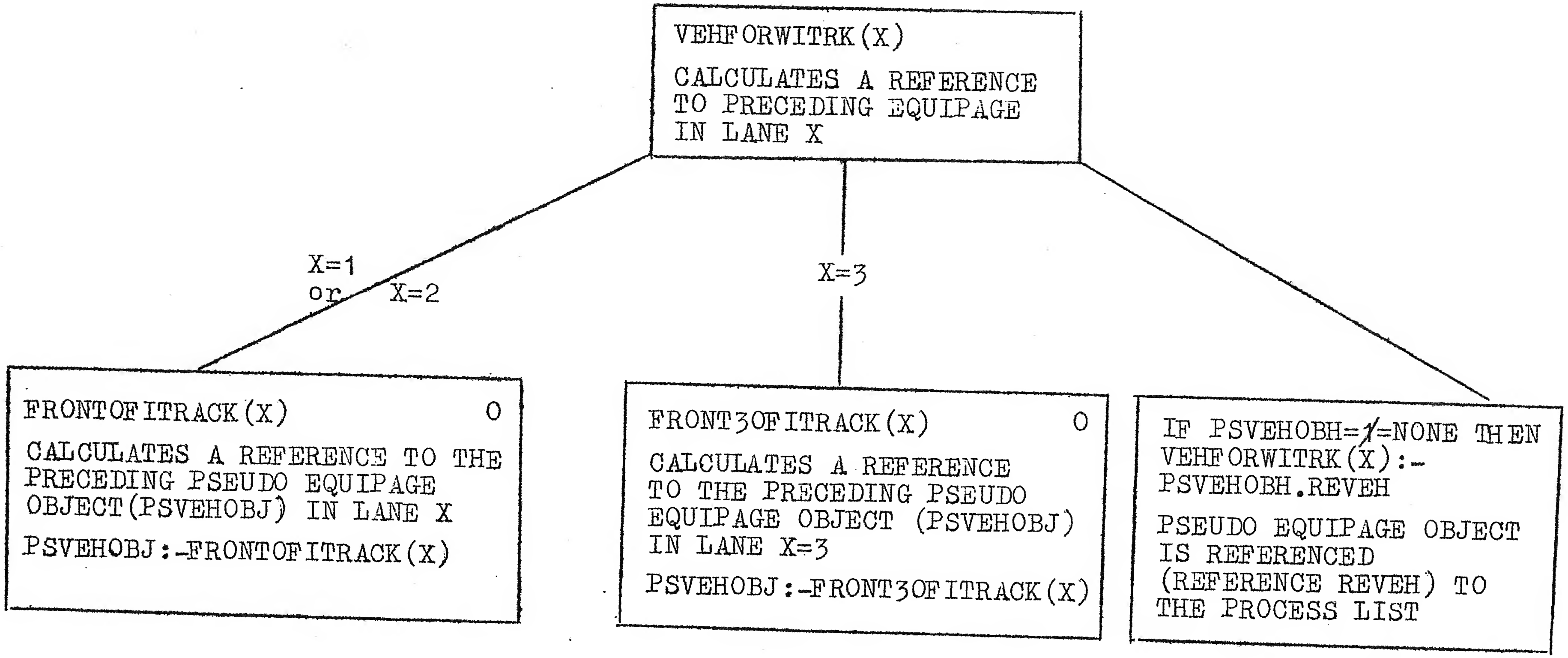
VEHFORWITRK(X)
CALCULATES A REFERENCE TO PRECEDING EQUIPAGE IN LANE X
X=1 or X=2
X=3
FRONTOFITRACK(X) 0
CALCULATES A REFERENCE TO THE PRECEDING PSEUDO EQUIPAGE OBJECT(PSVEHOBJ) IN LANE X
PSVEHOBJ:-FRONTOFITRACK(X)
FRONT3OFITRACK(X) 0
CALCULATES A REFERENCE TO THE PRECEDING PSEUDO EQUIPAGE OBJECT (PSVEHOBJ) IN LANE X=3
PSVEHOBJ:-FRONT3OFITRACK(X)
IF PSVEHOBH=/=NONE THEN VEHFORWITRK(X):-PSVEHOBH.REVEH
PSEUDO EQUIPAGE OBJECT IS REFERENCED (REFERENCE REVEH) TO THE PROCESS LIST

FIG. 3.2 (A)

FRONTOFITRACK(X)

CALCULATES A REFERENCE TO THE PRECEDING PSEUDO EQUIPAGE OBJECT(PSVEHOBH) IN LANE X(1 OR 2)

DETERMINE :

1. CATEGORY OF THE CURRENT EQUIPAGE S3:=CAT
2. ROAD COORDINATES OF CURRENT EQUIPAGE AT CLOCK TIME 'TIME' S1:=PREDS(CURRENT)

PSVEHOBJ:-TRACK(DIRNU,X).LAST

CALCULATES REFERENCE TO THE LAST PSEUDO EQUIPAGE OBJECT IN TRACK X WITH THE DIRECTION OF TRAVEL-DIRNU(OF CURRENT OBJECT)

WHILE

(1) THERE IS NO PSEUDO EQUIPAGE OBJECT (PSVEHOBJ==NONE) AND

(2) THE COORDINATE OF THE PSEUDO OBJECT AT THE CLOCK TIME 'TIME' ARE LESS THAN OR EQUAL TO THAT OF CURRENT OBJECT i.e. PREDS(PSVEHOBJ.REVEH)<=S1

PSVEHOBJ:-PSVEHOBJ.PRED *

CALCULATES REFERENCE TO THE PRECEDING PSEUDO EQUIPAGE OBJECT

DETERMINE CATEGORY OF PSEUDO OBJECT
S4:=PSVEHOBJ.REVEH.CAT

TEST FOR INTERACTION BETWEEN CURRENT VEHICLE OF CATEGORY S3 AND PSEUDO OBJECT OF CATEGORY S4

WHILE NO INTERACTIONS

PSVEHOBJ:-PSVEHOBJ.PRED*
S4:=PSVEHOBJ.REVEH.CAT

FRONTOFITRACK(X):-PSVEHOBJ

FIG. 3.2 (B)

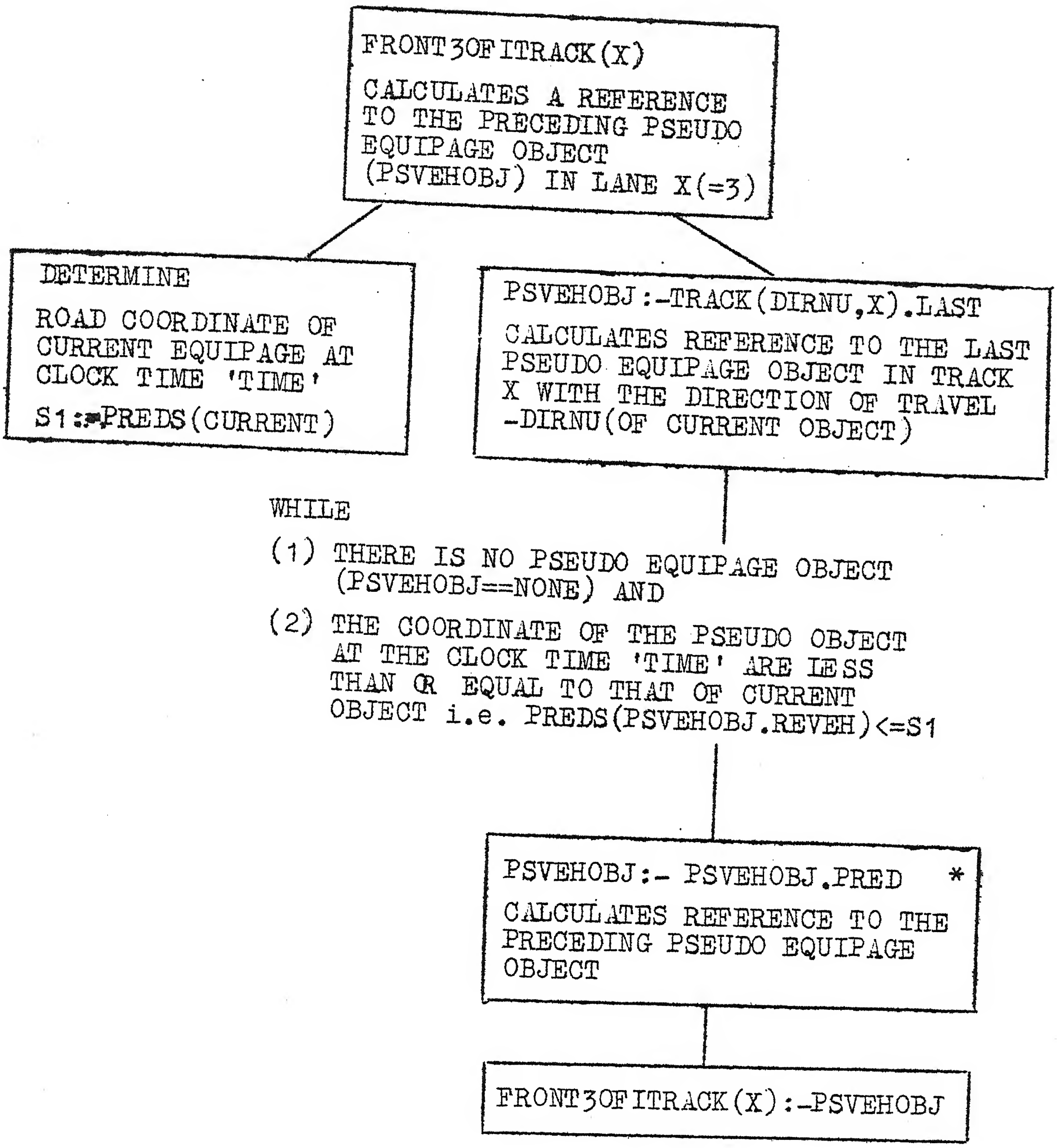

FIG. 3.2 (C)

FIG. 3.2 FLOW CHART FOR CALCULATING A REFERENCE TO PROCEDING EQUIPAGE OBJECT

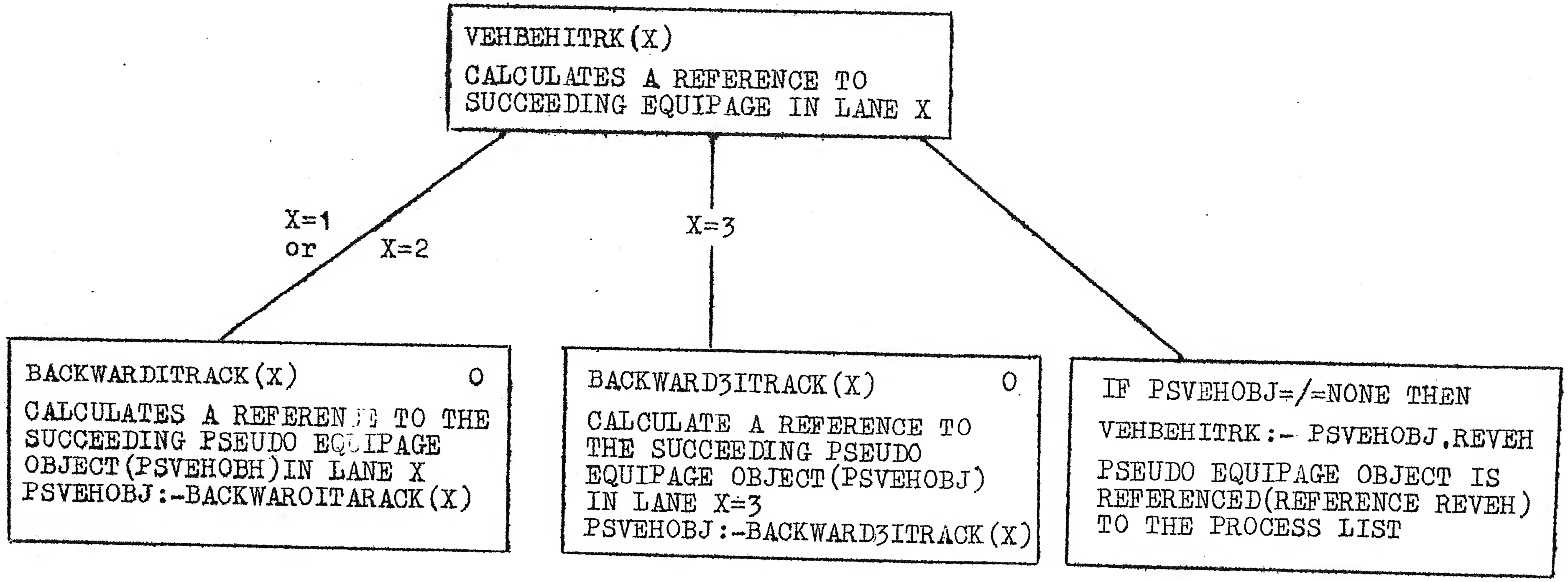
VEHBEHITRK(X)
CALCULATES A REFERENCE TO SUCCEEDING EQUIPAGE IN LANE X
X=1 or X=2
X=3
BACKWARDITRACK(X)
O
CALCULATES A REFEREN E TO THE SUCCEEDING PSEUDO EQ IPAGE OBJECT(PSVEHOBH)IN LANE X
PSVEHOBJ:-BACKWAROITARACK(X)
BACKWARD3ITRACK(X)
O
CALCULATE A REFERENCE TO THE SUCCEEDING PSEUDO EQUIPAGE OBJECT(PSVEHOBJ) IN LANE X=3
PSVEHOBJ:-BACKWARD3ITRACK(X)
IF PSVEHOBJ=/=NONE THEN
VEHBEHITRK:- PSVEHOBJ.REVEH
PSEUDO EQUIPAGE OBJECT IS REFERENCED(REFERENCE REVEH) TO THE PROCESS LIST

FIG. 3.3 (A)

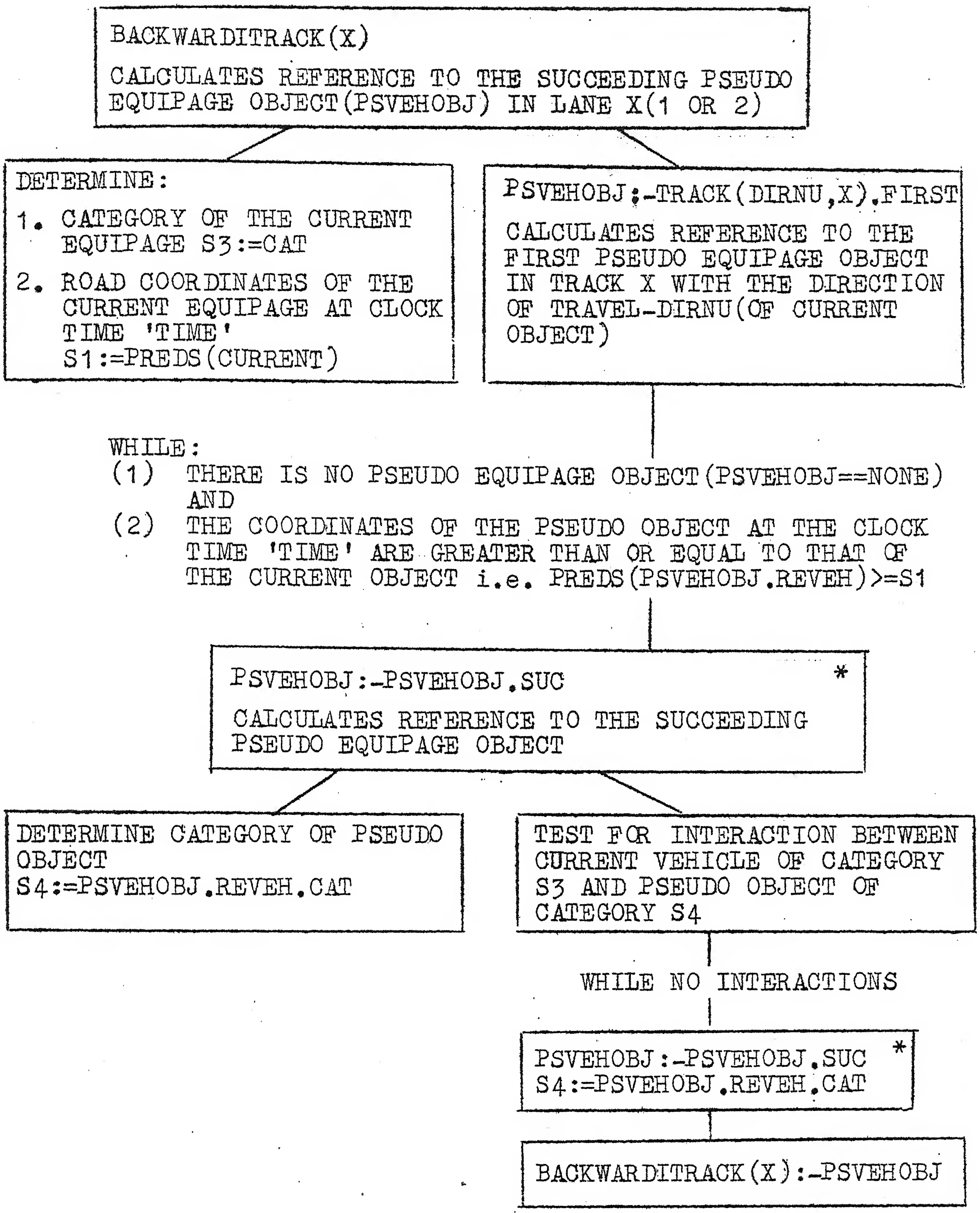
BACKWARDITRACK(X)
CALCULATES REFERENCE TO THE SUCCEEDING PSEUDO EQUIPAGE OBJECT(PSVEHOBJ) IN LANE X(1 OR 2)
DETERMINE:
1. CATEGORY OF THE CURRENT EQUIPAGE S3:=CAT
2. ROAD COORDINATES OF THE CURRENT EQUIPAGE AT CLOCK TIME 'TIME' S1:=PREDS(CURRENT)
PSVEHOBJ:-TRACK(DIRNU,X).FIRST
CALCULATES REFERENCE TO THE FIRST PSEUDO EQUIPAGE OBJECT IN TRACK X WITH THE DIRECTION OF TRAVEL-DIRNU(OF CURRENT OBJECT)
WHILE:
(1) THERE IS NO PSEUDO EQUIPAGE OBJECT(PSVEHOBJ==NONE) AND
(2) THE COORDINATES OF THE PSEUDO OBJECT AT THE CLOCK TIME 'TIME' ARE GREATER THAN OR EQUAL TO THAT OF THE CURRENT OBJECT i.e. PREDS(PSVEHOBJ.REVEH)>=S1
PSVEHOBJ:-PSVEHOBJ.SUC *
CALCULATES REFERENCE TO THE SUCCEEDING PSEUDO EQUIPAGE OBJECT
DETERMINE CATEGORY OF PSEUDO OBJECT S4:=PSVEHOBJ.REVEH.CAT
TEST FOR INTERACTION BETWEEN CURRENT VEHICLE OF CATEGORY S3 AND PSEUDO OBJECT OF CATEGORY S4
WHILE NO INTERACTIONS
PSVEHOBJ:-PSVEHOBJ.SUC *
S4:=PSVEHOBJ.REVEH.CAT
BACKWARDITRACK(X):-PSVEHOBJ

FIG. 3.3 (B)

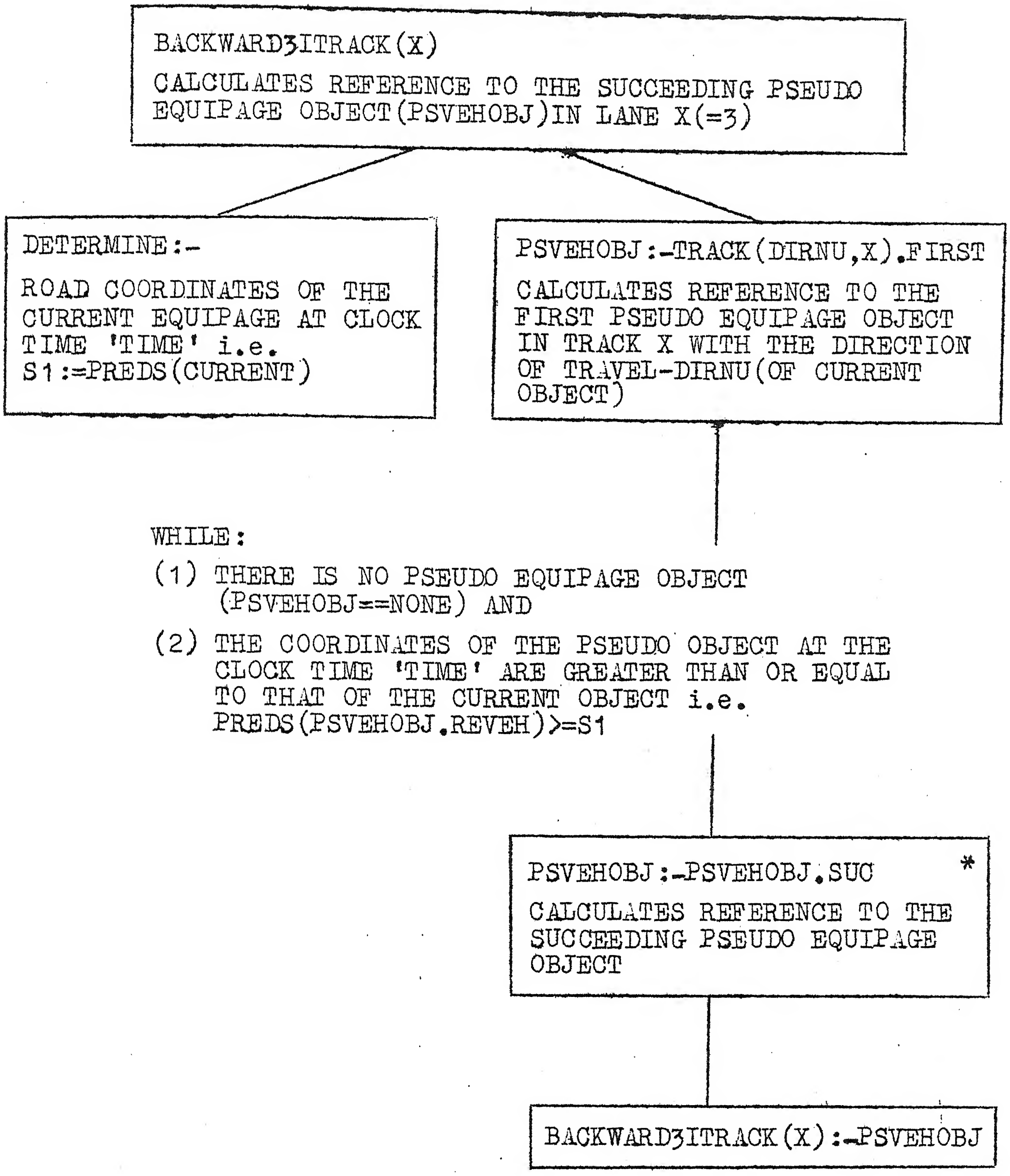

FIG. 3.3 (C)

FIG. 3.3 FLOW CHART FOR CALCULATING A REFERENCE TO SUCCEEDING EQUIPAGE OBJECT

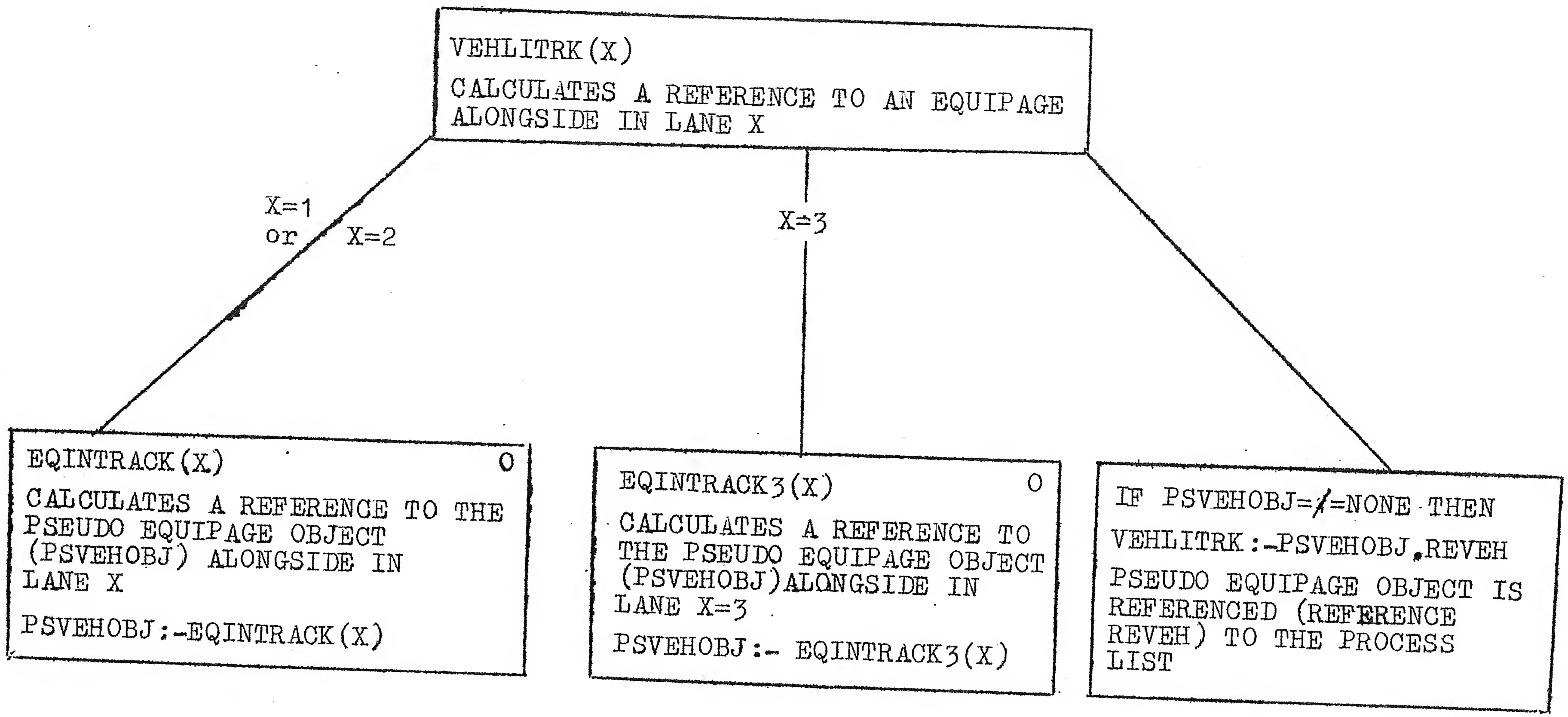
VEHLITRK(X)
CALCULATES A REFERENCE TO AN EQUIPAGE ALONGSIDE IN LANE X
X=1 or X=2
X=3
EQINTRACK(X) O
CALCULATES A REFERENCE TO THE PSEUDO EQUIPAGE OBJECT (PSVEHOBJ) ALONGSIDE IN LANE X
PSVEHOBJ:-EQINTRACK(X)
EQINTRACK3(X) O
CALCULATES A REFERENCE TO THE PSEUDO EQUIPAGE OBJECT (PSVEHOBJ) ALONGSIDE IN LANE X=3
PSVEHOBJ:- EQINTRACK3(X)
IF PSVEHOBJ=/=NONE THEN
VEHLITRK:-PSVEHOBJ.REVEH
PSEUDO EQUIPAGE OBJECT IS REFERENCED (REFERENCE REVEH) TO THE PROCESS LIST

FIG. 3.4 (A)

EQINTRACK(X)

CALCULATES REFERENCE TO THE PSEUDO EQUIPAGE OBJECT(PSVEHOBJ)ALONGSIDE IN LANE X(1 OR 2)

DETERMINE:

1. CATEGORY OF THE CURRENT EQUIPAGE S3:=CAT
2. ROAD COORDINATES OF THE CURRENT EQUIPAGE AT CLOCK TIME 'TIME' S1:=PREDS(CURRENT)

PSVEHOBJ:-TRACK(DIRNU,X).FIRST

CALCULATES REFERENCE TO THE FIRST PSEUDO EQUIPAGE OBJECT IN TRACK X WITH THE DIRECTION OF TRAVEL DIRNU(OF CURRENT OBJECT)

WHILE:

(1) THERE IS NO PSEUDO EQUIPAGE OBJECT(PSVEHOBJ==NONE) AND

(2) THE COORDINATES OF THE PSEUDO OBJECT AT THE CLOCK TIME 'TIME' ARE GREATER THAN THAT OF THE CURRENT OBJECT i.e. PREDS(PSVEHOBJ.REVEH)>S1

PSVEHOBJ:- PSVEHOBJ.SUC *

CALCULATES REFERENCE TO THE SUCCEEDING PSEUDO EQUIPAGE OBJECT

DETERMINE CATEGORY OF PSEUDO OBJECT S4:=PSVEHOBJ.REVEH.CAT

TEST FOR INTERACTION BETWEEN CURRENT VEHICLE OF CATEGORY S3 AND PSEUDO OBJECT OF CATEGORY S4

WHILE NO INTERACTIONS

PSVEHOBJ:- PSVEHOBJ.SUC*
S4=PSVEHOBJ.REVEH.CAT

EQINTRACK:-PSVEHOBJ

FIG. 3.4 (B)

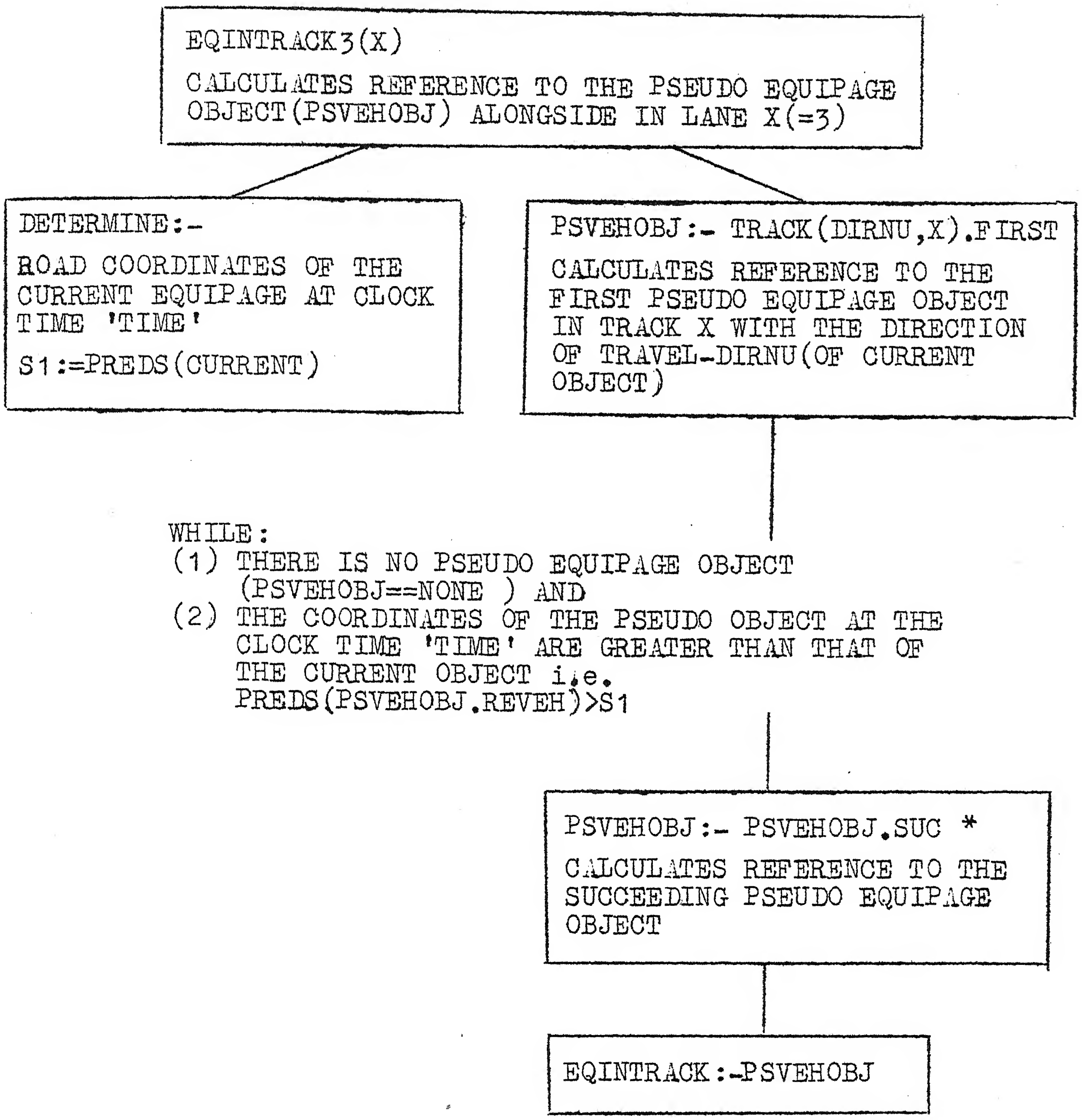

FIG. 3.4 (C)

FIG. 3.4 FLOW CHART FOR CALCULATING A REFERENCE TO ALONGSIDE EQUIPAGE OBJECT

The VTI simulation process reactivates the preceding and succeeding vehicles a number of times while deciding the operating mode for the current vehicle. This reactivation does not consider the types of the current vehicle and the reactivated vehicles ahead or behind it, which are likely to interact with the current vehicle and thereby affect its operating mode. This interaction depends upon the category of the current vehicle and that of the reactivated vehicle. The program was modified at a number of places so that only those vehicles which interact with the current vehicles are reactivated.

3.4.3 Overtaking Submodel

When a faster vehicle catches up with a slower vehicle along the road, this leads to overtaking/passing or following. Flying overtaking results when overtaking starts as soon as faster vehicle catches up with the slower vehicle. When flying overtaking is not permitted the faster vehicle starts following the slower vehicle and accelerative overtaking is carried out as soon as the opportunity arises.

When there are no hardshoulders with the road overtaking can take place as per VTI model if the following holds:

(i) The following vehicle has sufficient power-weight coefficient (or acceleration ability to carry out an

overtaking). The model allows the vehicle to overtake only if the acceleration ability at a running speed is greater than 0.25 meter per $sec.^2$ Acceleration ability of a vehicle at a certain speed depends upon the power-weight ratio, rolling and air resistances etc. For mixed traffic conditions it may not be possible for some of the vehicles, to have acceleration ability of 0.25 $meter/sec.^2$ but still it may like to overtake. The programme was modified so that any vehicle with a positive acceleration ability at a particular speed is permitted to overtake. When detailed field data are available it may be possible to recalibrate the acceleration ability depending upon the category of the vehicle.

(ii) The difference between desired speed classes is sufficiently great. The model allows overtaking when this difference is more than one (SPCLDIFF > = 1).

(iii) There is no overtaking prohibition.

(iv) Space for overtaking is available with regard to the surrounding equipages travelling in the same direction.

When there are hard shoulders overtaking can take place by passing which means the leading vehicle moves on to the shoulders and allows the following vehicle to pass. Overtaking takes place with a probability depending upon- the impeding vehicle's type and speed; available sight

distance and oncoming vehicles within the sight distance at hand.

The probability of accepting a gap of given length in order to overtake is required by the model in 32 different overtaking situations already described in Chapter 2.

The literature for VTI model indicates that the probability of overtaking depends upon the type of vehicle being overtaken (all motor vehicles, classified into 4-types). It does not consider the type and speed of overtaking vehicle for determining the probability of overtaking in a given situation. However a close look at the computer programme indicates that it is not the type of vehicle being overtaken but the type of overtaking vehicle that affects the probability of overtaking. It is proposed to seek this clarification from the authors of the model. The version in the computer programme sounds more reasonable and it is the overtaking vehicle which plays the dominant role in accepting a given overtaking opportunity. May be this discrepancy has occured during translating the model description from Swedish to English version.

The overtaking process in the mixed traffic flow is quite complex because of the large variations in the attributes of different categories of vehicles. It is

rightly suggested in VTI model that the probability of overtaking in a given situation depends upon;

(1) the overtaking manoeuvre type i.e. flying or accelerative;

(2) limitation to overtaking i.e. oncoming vehicle or sight distance;

(3) roadwidth, presence or not of hard shoulders;

(4) type of overtaking vehicle.

It is not sufficient to only consider the type of overtaking vehicle while making overtaking decision as it oversimplifies a complex process. For instance, a car overtakes another car in one case and it overtakes a bullock-cart in another, the probability of overtaking in these two cases for a given gap size will be significantly different because the closing rate in case of overtaking the bullock-cart is much less compared to that while overtaking a car. It thus seems plausible that the type of the vehicle being overtaken be also considered along with the type of overtaking vehicle in making the overtaking decision. During overtaking the overtaking vehicle is likely to move over to the wrong lane. The overtaking may be restrained if an oncoming vehicle interacts with the overtaking vehicle. The gap size accepted by overtaking vehicle also depends upon the speed of the oncoming vehicle. For slow moving oncoming vehicles

the closing rate is less and a smaller gap size may be acceptable. Alongwith speed the category of oncoming vehicle also plays a significant role in deciding for over- taking. If the oncoming vehicle occupies very slender width then even a small gap size may be accepted for overtaking as the overtaking and the oncoming vehicles may not interact. For example, when a car overtakes a scooter an oncoming scooter may not interact with it, but an oncoming bullock-cart may restrain the overtaking operation.

The above discussion indicates that it is desirable to consider the category of overtaking vehicle, category of overtaken vehicle and the category of the oncoming vehicle while making the overtaking decision. The combined effect of the three tells whether overtaking would be restrained or not by the oncoming vehicle and what would be the probability thereof.

In those cases where there is no oncoming vehicle and the limitation is only due to the sight distance the combination of the categories of overtaking and overtaken vehicles must be considered for making the overtaking decision.

Modified Overtaking Submodel: In the modified submodel in all there are $7^3 (= 343)$ combinations of overtaking, overtaken and oncoming vehicle

categories, some of which restrain the overtaking while others do not. All those combinations which do not restrain overtaking are listed in Table 3.6. These combinations have been incorporated in the modified model. While deciding for overtaking the category of oncoming vehicle is compared with those of overtaking and overtaken vehicles. Only in case of those oncoming vehicles which may restrain the overtaking, the gap size is determined. It sometimes so happens that oncoming vehicles are of such categories that they do not restrain the overtaking. In such a case, the limitation to overtaking is only due to sight distance. The combination adaoted in Table 3.6 may be modified as and when detailed field data are available.

The probability of accepting a gap X is evaluated in VTI model as follows:

$$p(x) = \begin{cases} 0 & \text{for } x \leq S_1 \\ a(x-S_1)/(S_2-x) & \text{for } S_1 < x < S_2 \\ a & \text{for } S_2 \leq x \end{cases}$$

where a, S_1, and S_2 are the calibration constants.

TABLE 3.6 COMBINATIONS OF OVERTAKING, OVERTAKEN AND ONCOMING VEHICLES WHICH DO NOT RESTRAIN THE OVERTAKING

Category of vehicle desiring to overtake	Category of vehicle to be overtaken	Category of oncoming vehicle which does not restrain the overtaking
Truck, car	Truck, car, horse-driven-cart, bullock-cart	Bicycle
Truck, car	Scooter, cycle-rickshaw, Bicycle	Scooter, Cycle-Rickshaw, Bicycle
Horse-driven-cart, Bullock-cart	Horse-driven-cart, Bullock-cart, cycle-rickshaw	Scooter, Cycle-rickshaw, Bicycle
Scooter	Truck, car	Scooter, Cycle-Rickshaw, Bicycle
Scooter	Scooter, cycle-rickshaw, Bicycle	All seven
Scooter	Horse-driven-cart, Bullock-cart	Scooter, Cycle - rickshaw, bicycle
Cycle-rickshaw	Horse-driven-cart, Bullock-cart	Scooter, cycle-ricksha Bicycle
Cycle-rickshaw	Cycle-rickshaw, cycle	Horse-driven-cart, Bullock-cart, Scooter, Cycle-rickshaw, Bicycle
Bicycle	Horse-driven-cart, Bullock-cart, cycle-rickshaw, bicycle	All seven

S_1 is the minimum (threshold) gap needed for overtaking. Any gap less than S_1 is rejected by all the vehicles. S_2 is the gap which is accepted with a probability a (the highest probability of overtaking). There is a linear relationship between probability of overtaking and gap sizes within the range S_1-S_2. VTI model considers 32 different overtaking situations and the gap acceptance relationships are tabulated for each situation.

For considering a very large number of overtaking situations in case of mixed traffic flow, VTI model is modified as follows, to determine the probability of accepting a gap size:

CASE I: When limitation is only due to sight length.

The probability of overtaking depends upon:

(1) Category of overtaking vehicle (T_1): 1-7

(2) Category of overtaken vehicle (T_2): 1-7

(3) Road width- (i) when there are hard shoulders > 2 meters
(ii) unpaved shoulders

(4) Type of overtaking- (i) Flying
(ii) Accelerative

The above results in 196 different situations. Gap acceptance relationships are needed for each of the combinations. The effect of vehicle being overtaken should be considered in terms of space occupied by it and its speed.

It is observed that some categories of vehicles with similar characteristics may be grouped together. It was decided to group the categories of overtaken vehicles into following five classes.

Group (1): Truck

(2): Car

(3): Horse-driven-cart, Bullock-cart and Cycle-rickshaw

(4): Scooter

(5): Bicycle

The above grouping reduces the overtaking combinations to (7x5x2x2)=140 and were adopted in the model. For each combination, the following are tabulated :

(i) LIMIT 3(T_1, GR_2, VB, OMT)- the minimum gap size needed to excute an overtaking. This corresponds to S_1 in VTI model ;

(ii) LIMIT 4 (T_1, GR_2, VB, OMT)- the gap size required for the highest probability of overtaking ;

(iii) OVERTAKEPR (T_1, GR_2, VB, OMT)- the highest probability of overtaking.

where, T_1 - category of overtaking vehicle

GR_2 - group to which the category of overtaken vehicle belongs (1-5)

VB - road width (1-2)

OMT - overtaking type (1-2) .

CASE II : When limitation is due to an oncoming vehicle.

In this case the probability of accepting a given gap size also depends upon the category of oncoming vehicles besides, other variables as listed in Case I. Then seven categories of the oncoming vehicles are grouped into 5 classes as done in CASE I . This results in 700 different overtaking situations. The programme uses the following gap acceptance parameters:

(i) LIMIT 1 (T_1, GR_2, GR_3, VB, OMT) - the minimum gap size needed to execute an overtaking ;

(ii) LIMIT 2 (T_1 , GR_2, GR_3, VB, OMT) - the gap size for the highest probability of overtaking ;

(iii) OVERTAKEPR (T_1, GR_2, GR_3, VB , OMT) - the highest probability of overtaking.

Here, GR_3 is the group to which the category (T_3) of oncoming vehicle belongs.

GR_3 = (1) for truck

(2) for car

(3) for horse-driven-cart, bullock-cart and cycle-rickshaw

(4) for scooter

(5) for bicycle

The other variables have the same meaning as in Case I.

The probability of accepting a given gap size (sight length or due to oncoming vehicle) is interpolated using the gap acceptance relationships for the 840 different overtaking situations. Random number is then generated to test for acceptance or rejection of the overtaking opportunity.

The modified version of the overtaking submodel, shown in Fig. 3.5, operates as follows:

(1) Calculate reference (VF) to the preceding vehicle in track no.2 that is likely to interact with the current vehicle.

(2) Determine category (T_1) of the current vehicle and category (T_2) of the preceding vehicle (VF).

(3) The current vehicle desires to overtake if the speed class difference of the two vehicles is more than one.

(4) Determine the sight-distance available to the current vehicle.

(5) Calculate reference to the oncoming vehicle (category T_3) which interacts with the current vehicle (category T_1) and leading vehicle (category T_2). The available distance to the oncoming vehicle from the current vehicle is also calculated. The above is determined for both track 1 and track 2 and the one with minimum distance is used.

(6) The type of limitation, that is, oncoming vehicle or sight distance that restrains the overtaking is identified.

WANT (OMT)
DETERMINES WHETHER A DESIRED OVERTAKING-FLYING OR ACCELERATIVE IS ACCEPTED OR NOT
OMT = 1 FOR FLYING OVERTAKING;
OMT = 2 FOR ACCELERATIVE OVERTAKING

...:- VEHFORWITRK (2)
...ALCULATES REFERENCE TO THE ...RECEDING VEHICLE THAT IS LIKELY ...O INTERACT WITH THE CURRENT ...EHICLE IN TRACK 2

DETERMINE THE CATEGORY (T1) OF THE CURRENT EQUIPAGE AND CATEGORY (T2) OF THE PRECEDING EQUIPAGE VF

TEST WHETHER CURRENT EQUIPAGE DESIRES TO OVERTAKE VF i.e.
SPCLASS- SPCLDIFF > = VF. SPCLASS

NO OVERTAKING DESIRED°
WANT: = FALSE

DETERMINE THE AVAILABLE SIGHT° LENGTH (SIGHT) AT THE POSITION OF THE CURRENT VEHICLE AND IN THE DIRECTION OF ITS TRAVEL

...NCOMBEHSIGHTITRK(1,T1,T2)
...ALCULATE:-
... REFERENCE TO THE PSEUDO EQUIPAGE OBJECT(PSV(1)) COMING FROM OPPOSITE...

ONCOMBEHSIGHTITRK (2,T1,T2)
CALCULATE:-
1. REFERENCE TO THE PSEUDO EQUIPAGE OBJECT(PSV(2))...

CALCULATE:-
1. MINIMUM SPACING BETWEEN THE CURRENT EQUIPAGE...

SIGHT LIMITATION PROCESS...

ONCOMING VEHICLE

WANT (OMT)
DETERMINES WHETHER A DESIRED OVERTAKING–FLYING OR ACCELERATIVE IS ACCEPTED OR NOT

DETERMINE THE GROUP TO WHICH CATEGORY OF VEHICLE BEING OVERTAKEN (T2) BELONGS

GR2=1 FOR T2=1(CAR)
=2 FOR T2=2(TRUCK)
=3 FOR T2=3,4,6 i.e. HORSE-DRIVEN-CART, BULLOCK-CART, AND CYCLE-RIKSHAW
= 4 FOR T2=5 (SCOOTER)
= 5 FOR T2=7 (BICYCLE)

INTERPOLATE THE PROBABILITY OF OVERTAKING WITH REFERENCE TO

(1) OVERTAKEPR (T1,GR2,VB,OMT)

HIGHEST PROBABILITY OF OVERTAKING FOR OVERTAKING VEHICLE (CATEGORY T1);VEHICLE BEING OVERTAKEN(GROUP GR2);ONCOMING VEHICLE (GROUP GR3);ROAD WIDTH (VB); AND TYPE OF OVERTAKING(OMT)-FLYING OR ACCELERATIVE

(2) MINIMUM GAP SIZE TO EXECUTE THE OVERTAKING LIMIT3(T1,GR2,VB,OMT).

(3) GAPSIZE REQUIRED FOR HIGHEST PROBABILITY OF OVERTAKING LIMIT4(T1,GR2,VB,OMT)

(4) AVAILABLE GAP i.e. SIGHT

DETERMINE THE GROUP TO WHICH CATEGORY OF VEHICLE BEING OVERTAKEN(T2) BELONGS

GR2=1 FOR T2=1(CAR)
=2 FOR T2=2(TRUCK)
=3 FOR T2=3,4,6 i.e. HORSE-DRIVEN-CART, BULLOCK-CART, AND CYCLE-RIKSHAW
=4 FOR T2=5 (SCOOTER)
=5 FOR T2=7 (BICYCLE)

DETERMINE THE GROUP TO WHICH CATEGORY OF ONCOMING VEHICLE(T3) BELONGS

GR3=1 FOR T3=1(CAR)
=2 FOR T3=2(TRUCK)
=3 FOR T3=3,4,6 i.e. HORSE-DRIVEN-CART, BULLOCK-CART, AND CYCLE-RIKSHAW
=4 FOR T3=5 (SCOOTER)
=5 FOR T3=7 (BICYCLE)

INTERPOLATE THE PROBABILITY OF OVERTAKING WITH REFERENCE TO

(1) OVERTAKEPR1((T1,GR2,GR3,VB,OMT)

HIGHEST PROBABILITY OF OVERTAKING FOR OVERTAKING VEHICLE(CATEGORY T1); VEHICLE BEING OVERTAKEN (GROUP GR2);ONCOMING VEHICLE (GROUP GR3);ROAD WIDTH(VB); AND TYPE OF OVERTAKING(OMT) -FLYING OR ACCELERATIVE

(2) MINIMUM GAP SIZE TO EXECUTE THE OVERTAKING LIMIT1(T1,GR2,GR3,VB,OMT)

(3) GAP SIZE REQUIRED FOR HIGHEST PROBABILITY OF OVERTAKING LIMIT2(T1,GR2,GR3,VB,OMT)

(4) AVAILABLE GAP TO ONCOMING VEHICLE i.e. ONCOSIGHT

GENERATE RANDOM

GENERATE RANDOM NUMBERS TO TEST

Sight distance limits the overtaking where the distance of the oncoming vehicle is more than the available sight distance or there is no oncoming vehicle of category which is likely to restrain the overtaking.

(7) Depending upon the type of limitation, the categories of overtaking, overtaken and oncoming vehicles, the probability of accepting a given gap is estimated.

(8) Random numbers are generated to test whether the available gap is accepted or not. If the available gap is not accepted the vehicle follows the leading one till it next encounters either a block limit where an extra lane begins, or a point of maximum sight distance.

3.4.4 Scanning of the Process

VTI model adopts event scanning in the simulation process. A number of traffic simulation models adopt periodic (uniform time increment) scanning whereas another model for single lane (Mukesh, 1980) adopts a combination of the two. Each method of scanning has its own merits and limitations. Without entering into any controversy let us say that any technique to be adopted should represent the real system and also be efficient.

VTI model claims to be more efficient in terms of computation time. In this model, an event occurs each time a vehicle passes any of the following points:

(1) A decision point for flying overtaking ;

(2) A decision point for accelerative overtaking;

(3) A point of overtaking (when the overtaking vehicle is at the same distance coordinate as the overtaken vehicle) ;

(4) A point where an overtaking finishes ;

(5) A block limit .

A close look at the model and the computer programme indicates that the choice of the decision point for accelerative overtaking presents some difficulties with reference to mixed vehicular traffic.

Once a vehicle cannot accept a flying overtaking, it follows and gets next overtaking opportunity when it encounters either of the following:

(i) A block limit where an extra lane begins ;

(ii) A point of maximum sight distance.

Fig. 3.6 indicates that a faster vehicle tests for flying overtaking in block 1 at F_2. If this opportunity is not accepted the vehicle continues to follow and the next overtaking opportunity occurs at F_3 in block 2, at the point of maximum sight distance. If this opportunity is also rejected then the vehicle will look for the next opportunity may be in block 3, if there is a point of maximum sight distance.

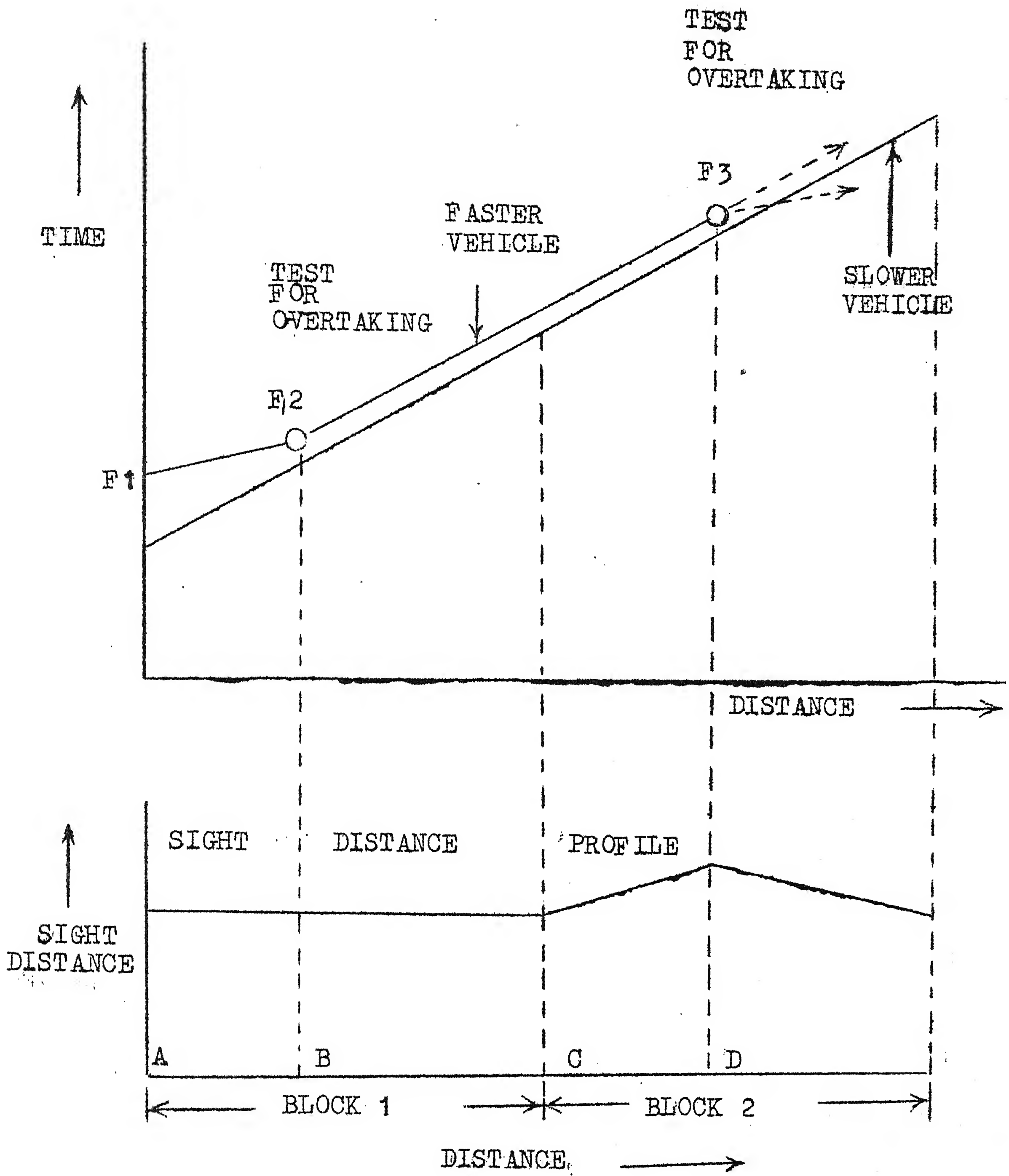

FIG 3.6 TEST FOR OVERTAKING OPPORTUNITIES

The above example illustrates that once an overtaking attempt is aborted, the faster vehicle starts following for quite some distance. In developed countries where there are only motor vehicles and there is not much difference in the free speeds of leading and following vehicles, the logic adopted in VTI model for testing of overtaking opportunity sounds quite reasonable. However, in India especially in plains and rolling terrains the faster vehicle while trying to overtake a slow moving vehicle does not wait till either an extra lane is encountered or a point of maximum sight distance is met. The faster vehicle is constantly on the look out of opportunity to overtake and limitations are more due to oncoming vehicles. A car supposing is unable to overtake a bullock-cart at the first opportunity while moving on a level tangent section. Even if this block extends over large distance further and there is no oncoming vehicle, VTI model does not provide an overtaking opportunity in that block. But in reality, the car will overtake as soon as it finds that oncoming vehicles are far away.

It seems therefore desirable to modify this aspect of VTI model by either of the following:

(i) periodic scanning of the following vehicles at short intervals so that a number of overtaking opportunities are tested,

(ii) dividing the homogeneous blocks into a number of parts so that the block lengths are reduced and many

overtaking opportunities may arise.

Case (ii), which is comparatively simple to include in VTI model structure was adopted. The main problem is arbitrariness in selecting the block length. It will be more appropriate if case (i) is included in the model so as to have a combination of periodic and event scanning.

3.5 Programme Design

The programme consists of two processes.

(i) Equipage generater process - PROCESS CLASS GENERATORPROCESS.

(ii) Equipage process named- PROCESS CLASSVEH.

3.5.1 Equipage Generator Process

This process creates objects (i.e. vehicles) and allots the driver-vehicle attributes. These equipages are defined by parameters like identity number, basic desired speed, power-weight ratio, speed class, vehicle type etc. Parameters giving traffic attributes consists of starting point, starting time, direction of travel etc. The generator process also activates the equipages at their starting time. The various equipage attributes are listed in Appendix II.

VTI simulation model programme indicates that various equipage attributes are predetermined and given as input to the equipage process. These attributes may have been determined from the actual field observations or generated

from various submodels. A number of attributes like headway gap distribution, basic desired speed distributions are probabilistic and data may be generated from the fitted distributions.

A separate computer programme was developed in SIMULA to generate the equipage attributes. The programme operates as follows:

(i) For each direction of travel the arrival times of the equipages are generated with the arrival gaps following a Negative Exponential or Erlang distributions. The programme can take care of any of these distributions.

(ii) The vehicle is assigned a category i. e. truck, car, horse-driven-cart, bullock-cart, scooter, cycle-rickshaw, bicycle. Using the composition of different categories of vehicles in the traffic flow, Uniformly distributed random numbers, as available for the SIMULA compiler, are generated.

(iii) Knowing the category of the equipage the basic desired speed is generated using the normally distributed parameters of that category.

(iv) Speed class, power-weight ratio are also assigned for each category of the equipages.

The above programme uses the various random drawing procedures as available in SIMULA language. The programme can be suitability modified for other types of distributions

which may be fitted to the field data.

3.5.2 Equipage Process

This describes all the possibilities that an equipage can have like moving freely, following a vehicle, overtaking a vehicle or being overtaken, lane change etc. This process is the kernel of the simulation model. The various procedures are modified in this process to account for the mixed traffic conditions. As the equipages move from one end to the other the times at which the next event of each equipage will occur are calculated. The events are then executed in chronological order.

For programming reasons an equipage belongs to one and only one list. Since the need arises for an equipage to belong to a further list besides the process list a pseudo equipage object from the class PSEVDOVEH has been created. These objects have the reference REVEH to their equipage.

The ordinary cycle for an arbitrary equipage is:

(i) Predict the time of the next event-NEWPRETIME

(ii) Await the predicted time-HOLD

(iii) Move the equipage in time and space-DRIVE.

The programme structure for the equipage class vehicle (VEH) is shown in Fig. 3.7.

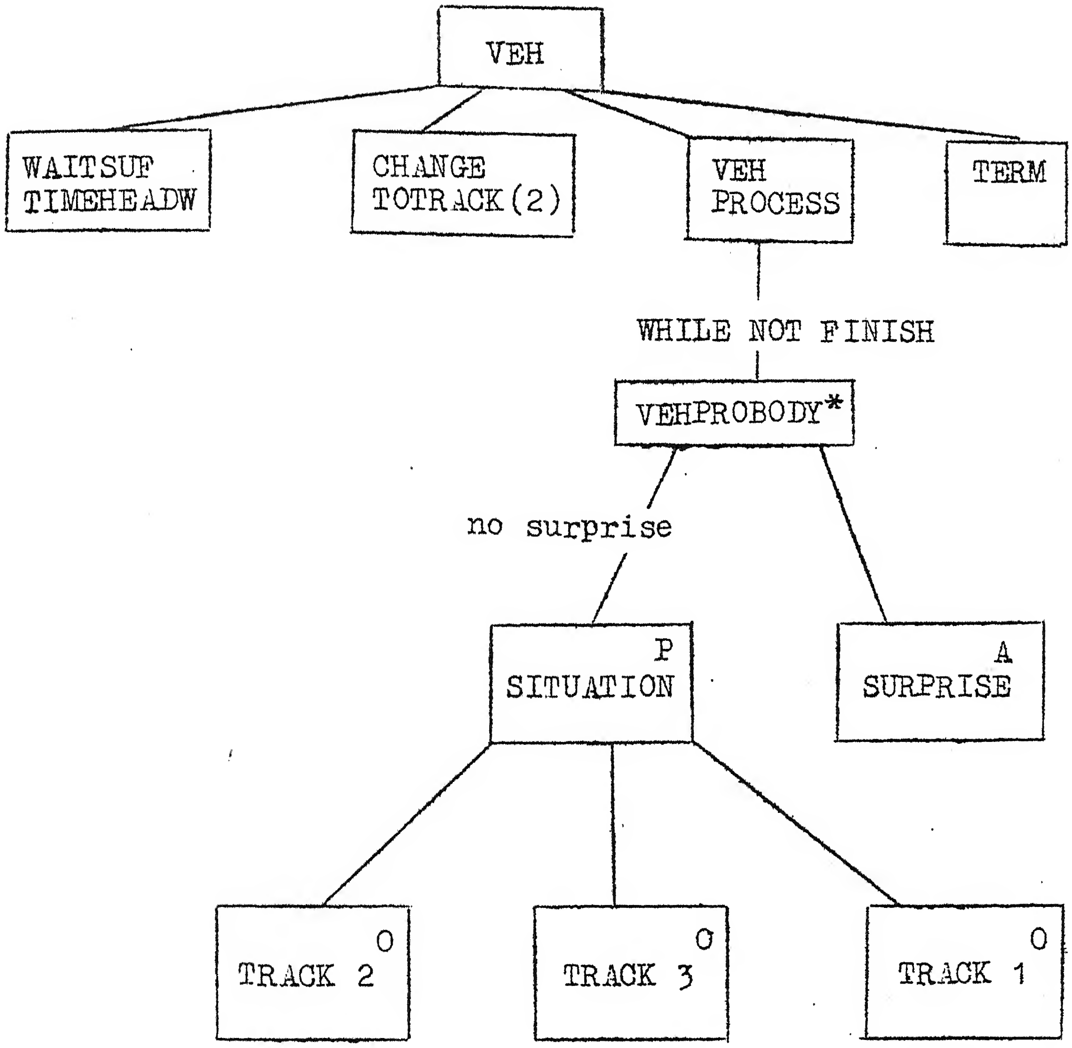

FIG. 3.7 : PROGRAM STRUCTURES FOR EQUIPAGES

Source : (Gynnerstedt , 1979)

3.6 Simulation Experiments

Computer programme of VTI model was modified as per changes already discussed in sections 3.3 and 3.4 . These changes relate to the vehicular attributes and the flow logics of mixed traffic conditions in India. Experience shows that in a complex traffic flow model a programmer may not be able to visualize the various eventualities in programming thereby getting results inconsistent with the desired logics. The special features of SIMULA also pose a host of problems while programming. It is thus desirable to test the simulated results to check whether the programme behaves in the desired fashion.

A number of simulation runs were taken with varying roadway characteristics and traffic conditions. The output of the simulated vehicles were plotted. In case of any inconsistanciesin the flow logics of the simulated vehicles the errors in the programme were identified and corrected. After a number of trials the output of the simulated vehicles was observed to follow the desired flow logics.

The simulation experiments were first conducted on a two kilometer long level tangent section having (1) paved shoulders, (2) unpaved shoulders, over the

entire length. These two cases were taken due to varying flow logics in them. The sight distance was first taken to be uniform over the entire length. It was found that in case of unpaved shoulders if an overtaking opportunity was once rejected then no more overtaking was tested in that road section. This was because there was no specified point of maximum sight distance and the road section consisted of only one homogeneous block. The results indicated that in such a case all the vehicles started following a slower vehicle. These problems arose due to scanning process already discussed in section 3.4.4. To get around this problem the road section with unpaved shoulders was divided into a number of homogeneous subsections each of 200 meter length with a point of maximum sight distance specified for each subsection. This was done to build in the realism as existed on the road. However, the selected length of the subsection was just arbitrary. This arrangement when simulated tested a series of overtaking opportunities either at a point of maximum sight distance or at the end of the subsections or blocks. The various programming problems that came in the way were successfully tackled. The simulated results as shown in Fig. 3.8 and 3.9 show that the vehicles follow the desired flow logics as formulated for the mixed

traffic conditions. A few more experimental runs were made on different roadway geometrics. However, the time-space diagram for them are not plotted. The output from the simulated experiment creates a file of events which gives the record of each event in terms of time of event, event type, the vehicle involved and their attributes etc. It is desirable to have separates output files for the simulated vehicles and also a file for the summary of results. These files will considerably help in analysis of the simulated data. The programme can be further modified so that the time-space diagram of the simulated vehicles is also plotted by the computer.

The objectives of the study were restricted to developing the flow logics for the mixed traffic conditions and incorporate them in VTI model without changing its basic structure. No detailed analysis of simulated results was planned. Once the various submodels are calibrated with the actual field data the simulation model as formulated in the study can be validated.

3.7 Applications of the Model

The simulation model can be gainfully applied in several ways for both analysis and design of traffic systems. Some of the outstanding applications are discussed below:

(i) First and the foremost application is in developing traffic flow relationships by studying the interactions between different categories of vehicles under varying volume levels, compositions, road geometry, surface type and road roughness. Since highway capacity is the maximum number of vehicles that can pass over a given section of lane or roadway during a given time period (mostly an hour) under prevailing roadway and traffic conditions, an estimate of the capacity can be made under different levels of service. This is an important design parameter. The level of service can be defined in terms of operating speed of different categories of vehicles, proportion of vehicles delayed, traffic interruption, freedom of manoeuvres, safety etc.

(ii) A study of minor improvements can be carried out by way of changing the roadway parameters like curvature, gradient, shoulder width, sight distance distribution etc. and observing the traffic flow pattern.

(iii) One of the recent applications of traffic flow simulation models is fuel consumption/emission studies. Fuel consumption is a function of factors like speed profile of the vehicle, traffic interactions and road geometry/profile etc. Fuel consumption/emission model can be calibrated by conducting a series of observations on various vehicles under different speed

and roadway conditions. The results obtained from the simulation experiments, like speed profile, can be used to estimate fuel consumption/emission as a function of traffic and roadway characteristics. These studies can also be used to evaluate operating costs of vehicles on a road under variegated traffic conditions.

4. SUMMARY AND CONCLUSIONS

A traffic simulation model describes the behaviour of traffic stream by considering in detail the behaviours of individual vehicles as they traverse a specified section of road. Of the various traffic simulation models that exist to date for two lane roads, VTI model stands out as most advanced and comprehensive. This model uses Jackson Structured Programming technique in systems and programming work. The programming language used is SIMULA-67 which has exceptional qualities for simulation as well as permits a lucid organization of the programme text and well structured data.

DEC 10/20 SIMULA compilers as available in a few installations in this country differ from SIMULA-67 in a number of respects. This necessitates a lot of changes in the documented programme of VTI model. About one third of the statements in the model were modified. A sample input output data listing obtained from VTI was immensely useful while debugging.

VTI model as it stands originally is framed for traffic conditions which are for too homogeneous and streamlined than the ones existing in India. Indian traffic conditions are extremely heterogeneous involving large variations in vehicle type, their attributes and

the flow pattern. This renders VTI model unanswerable to the Indian conditions. It is therefore intended to modify the model to incorporate the flow logics associated with mixed traffic flow.

The traffic has been divided into seven categories namely truck, car, scooter, horse-driven-cart, bullock-cart, cycle-rickshaw and bicycle. These seven categories represent wide variations in the speed and dimensional characteristics of the vehicles. It may be desirable to include a few more categories of vehicles like auto-rickshaws, mini-bus etc. The modified structure of the model is such that any category of vehicles can be easily incorporated once the vehicular characteristics are well defined. In the programme the object (vehicle) has a number of attributes. An additional attribute of the object which defines the category of the object has been included in the programme structure to account for different categories of vehicles. The values of various attributes of these vehicles like desired speed, air-resistance, power-weight ratio, acceleration/deceleration rates have been revised. These values may be suitably modified when the detailed field data are available.

In VTI model each vehicle is alloted a speed class in the desired speed distributions (divided into 25 classes). In case of mixed traffic flow it is thought

desirable to have a separate distribution for each category of vehicle. Using these distributions the basic desired speed for each vehicle is generated. Depending upon the category of vehicle and its basic desired speed it is also assigned a speed class. The free speed profile of the vehicle over entire length of the road section is then determined using the characteristics of different homogeneous road blocks.

Interaction model for the mixed traffic flow is quite complex to formulate due to large variations which result in various types of interactions between the fast and slow moving vehicles. VTI model decides about the overtaking, passing or following mode when a vehicle is close to another in the same track. In mixed traffic flow, at times, two or more vehicles may be travelling at their free speeds in one lane width without any interaction. The interaction between the vehicles travelling in the same track thus depends upon the categories of the vehicles. The model is so modified that whenever it is necessary to calculate a reference to a vehicle travelling behind, travelling ahead or travelling alongside, test for interaction is resorted to. This interaction depends upon the category of the current vehicle and that of the reactivated vehicle. Various combinations of vehicles that interact in a lane

are formulated. The programme is so modified that only those vehicles which interact with the current vehicle are reactivated.

The overtaking process in the mixed traffic flow is extremely involved. It is seen that it is not sufficient to consider only the type of overtaking vehicle while making overtaking decision as is done in VTI model. It is desirable to consider the categories of overtaking vehicle, overtaken vehicle and the oncoming vehicle while making the overtaking decision. In those cases where there is no oncoming vehicle and the limitation is only due to sight distance, the combination of categories of overtaking and overtaken vehicle must be considered for making the overtaking decision. Various combinations of categories of overtaking, overtaken and oncoming vehicles which do not restrain the overtaking operation are formulated in the study. These combinations help in deciding whether the overtaking/passing is likely to be restrained or not.

VTI model considers 32 different overtaking situations and the gap acceptance relationships are tabulated for each. For considering a very large number of overtaking situations in case of mixed traffic flow the model is so modified that the probability of accepting

an overtaking for a gap size depends upon type of overtaking (flying or accelerative), roadwidth (paved or unpaved shoulders), category of overtaking vehicle, category of overtaken vehicle and category of oncoming vehicle. By grouping some of the categories of vehicles it is possible to have 140 overtaking combinations when limitation is due to sight distance and 700 combinations when limitation is due to oncoming vehicle. The probability of accepting a given gap size (due to sight distance or oncoming vehicle) is interpolated using the gap acceptance relationship for the 840 different overtaking situations.

The model adopts event scanning in the simulation process. The choice of the decision point for accelerative overtaking presents some difficulties with reference to mixed traffic. It seems desirable to modify this aspect of the model by either of (1) periodic scanning of the following vehicle at short intervals, so that a number of overtaking opportunities are tested or (2) dividing the homogeneous blocks into a number of parts so that the block lengths are reduced and many overtaking opportunities may arise. Case (2) which is comparatively simple to include in VTI model structure is adopted. The main problem is arbitrariness in selecting the block length.

The programme indicates that various equipage attributes are predetermined and given as input to the equipage process. A separate computer programme is developed in SIMULA language to generate the equipage attributes. This programme uses the various random drawing procedures as available in SIMULA language. The programme can be suitably modified for other types of distributions which may be fitted to the field data.

The computer programme of VTI model is modified to incorporate all the changes discussed above. These changes relate to the vehicular attributes and the flow logics of mixed traffic conditions in India. The simulation experiments were first conducted on a two kilometer long level tangent section having (1) paved shoulders, (2) unpaved shoulders, over the entire length. The simulated results show that the vehicles follow the desired flow logics as formulated for the mixed traffic conditions. Once the various submodels are calibrated with the actual field data the simulation model as formulated in the study can be validated. The modified model is flexible enough for introducing the changes, related to vehicular attributes and flow logics, that may be desirable for different road traffic setups.

The model can be applied for research, planning and design in Traffic Engineering in multiple ways. Some

of the prominent applications are study of interactions between vehicles and road geometry thereby establishing traffic flow relationships and road capacities at various levels of service; study of minor improvements and estimation of fuel consumption/emission as functions of traffic and roadway characteristics.

In nutshell, this study aims at modifying VTI model to incorporate the flow logics associated with mixed traffic flow thereby studying the traffic flow behaviour under varying road and traffic conditions. Moreover, the study intends to create a platform for development of a comprehensive traffic simulation model for Indian conditions.

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APPENDIX I

SIMULA LANGUAGE

Source: 1. Birtwistle, G.M. et al. 'SIMULA Begin' Auerbach Publishers Inc. Philadelphia Pa, 1973.

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1. Introduction

SIMULA-67 is a true extension (i.e. a superset) of ALGOL-60 . It was originally implemented on UNVAC 1107 in early 1965; and has since been implemented on many other computers including Burroughs B 5500; CDC 3000/6000 Series; IBM 360/370 Series and DEC 10/20 Systems. The language was designed to provide simulation facilities without loosing advantage of a powerful general-purpose language. Just as GPSS and SIMSCRIPT are the two most popular discrete simulation languages in U.S.A., SIMULA appears to be most popular in Europe.

SIMULA though based on ALGOL 60 has additional facilities like record-oriented dynamic memory allocation; reference (pointer) structure; sets and queues; text and character handling; sequential and direct access input-output; quasi-parallel sequencing (coroutines) and process (event) oriented simulation capabilities. It is designed in

a way which makes it easy to produce perspicuous, well-structured, readable and secure programmes. SIMULA-67 is w ell adapted to structured programming methodology.

The framing of a problem for computer solution takes place in two phases. The first 'design phase' consists of analysing the problem, decomposing it into its components, classifying these components and planning the flow of computation. The second phase is 'coding', that is, expressing the plan of phase one in a programming language. With many programming languages this will amount to complete rewriting, as the natural human modes of decomposition and classification are not available within the language. This is not the case with SIMULA where concepts for a given problem area can be formulated directly in the language itself. Thus SIMULA is more than just a notation for describing computing processes- it also provides a framework for concept creation and is a tool of thought in problem analysis. SIMULA has been designed to trap as many errors as possible at compile time. Here the object programme (programme translated during compilation) is executed supported by prewritten routines called the 'run time system' (RTS). This step is called 'run time'. At run time the programme data is read in when needed and results printed out when requested in the programme. Any errors occuring at run time are called 'run time errors'.

DEC 10/20 SIMULA version has also a very powerful on line debugging system called SIMDDT.

2. Some Important Components of SIMULA

(i) Object: Object is a single entity to combine data and action associated with a component of a system. An object in general consists of three parts:

- a heading identifying an object
- a data structure
- an action pattern

(ii) Object Generator: In SIMULA the key word NEW followed by the name of the object to be generated is called an object generator, e.g. the object generator NEW CUSTOMER creates a new CUSTOMER-object every time it is executed.

(iii) Variable: A variable is an entity which consists of a name; a value; a type. The name and type of a variable is fixed once and for all. The value however may be changed any number of times by means of assignment operations. When a new value has been assigned to a variable the old value is lost.

(iv) Reference Variable: This is an important feature of SIMULA. It has the form:

REF (Qualification) Variable, e.g.

REF (CUSTOMER-Object) FIRST would make reference to the first customer in the QUEUE object.

(v) Genetive Notation: It is quite often used in SIMULA just as they are common in ordinary language. In SIMULA generative is represented by a '.' (dot) instead of the informal 's in ordinary languages, e.g. FIRST. NEXT. NEXT, etc.

(vi) Blocks: The block is a central mechanism of SIMULA. It has the following form:

```
BEGIN  declarations;
       statements;
END
```

The declarations of a block describe quantities such as variables, arrays, etc. The statements describe operations to be performed. The declarations introduce a nomenclature valid within the textual scope of the block referring to quantities which exist during execution of an instance of the block. The quantities are called 'local' quantities.

A block is itself a statement and therefore may be part of another block. This textual nesting may be carried out to any depth. As far as reference to local quantities are concerned a block is completely self contained and decomposed from its programme environment; however it may interact with its environment by referring to global quantities (those local to textually enclosing blocks). The

binding rules ensure that any reference to a local quantity is correctly interpreted regardless of the environment of the block. Thus the block concept corresponds to the intuitive notation of a 'sub-problem' and is a useful unit of programme composition. It provides a way of splitting a large programme into either (1) independent blocks each able to function correctly in different environments (if all quantities referred to are local), or (2) blocks which can be written with minimum of assumptions on their environment.

Such decompositions are especially important if more than one person takes part in the analysis and programming of a problem.

(vii) Procedure: Procedures can be likened to what are called 'subroutines' in FORTRAN. It has two parts:

(1) PROCEDURE - heading and

(2) PROCEDURE - body

We define the block as the body of a procedure by writing a procedure heading in front of the block. For example,

```
PROCEDURE HISTOGRAM (A, LOWER, UPPER);
          INTEGER ARRAY A;
BEGIN  )
- - -  }  PROCEDURE- body (block)
END    )
```

Where HISTOGRAM serves to name the PROCEDURE-body and thereafter follows a list of the formal parameters in paranthesis (A, LOWER, UPPER) and then a list of 'specifications' which gives the type of each formal parameters. The specifications need not be in the same order as formal parameter-list but every formal parameter must be specified. Then follows the PROCEDURE-body in the form of a block which performs the desired action. In order to invoke the activation of a procedure (or to 'call' it) we merely have to write the name of the procedure and supply a parenthesized list of actual parameters which must correspond to the formal parameter list in number, order and be of compatible types. Note that it is possible to declare procedures with no parameters. To call such a procedure we need merely write its name.

(viii) Class: A CLASS- declaration describes those properties which are common to every object of the class and which are not subject to change during the object life span. A CLASS-declaration serves as a fixed enbloc description and consists of the following three items which correspond to the main parts of the object:

(1) A CLASS-heading containing the key word CLASS and the name of the class.

(2) A declaration list which describes the data structure of an object of this class by stating the type

and name of each local variable (but not their values since they are defined individually for each object and may change with time). Entities other than variables may also be defined in the declaration list e.g. reference variable.

(3) A statement list which describes the action pattern of each object of the class. The declaration list and the statement list are bracketed together by a BEGIN-END pair, forming what is called the CLASS-body. A CLASS-body is an instance of a general construction called a block.

BEGIN declaration list; Statement list END

The parameters of CLASS are mentioned in the CLASS-heading itself and their types and names are also declared right there.

(ix) Class Simulation: SIMULA is provided with a predefined system CLASS SIMULATION which contains all the necessary concepts for queues and active and passive components. When the identifier SIMULATION is used to prefix a block, these concepts become available to the user. There are three classes of prime importance within SIMULATION.

(1) PROCESS: The quantitative description of a process has a static part- a sequence of attribute declarations and a dynamic part- a sequence of statements,

called an 'operation rule' describing the dynamic behaviour of the process. A process performs its operations in group classed 'active phase'. A process carries data and executes action. There is also a mechanism which activates and deactivates events belonging to the process. In a simulation study we may deal with several processes that have the same data structure and operation rule but differ in the values of attributes related to the data structure. Such a group of alike processes is called PROCESS CLASS.

(2) LINK : They prefix CLASSES whose objects are to be placed in, and removed from queues.

(3) HEAD: Serves as the head of a queue.

(x) Random Drawing Procedures: SIMULA-67 provides 10 random number procedures for drawing samples from different probability distributions including Uniform, Exponential, Normal, Poisson and Erlong distributions.

3. An Elementary View of Input and Output

In SIMULA a deck of cards may be thought of as a continuous stream of numbers, separated by blanks or by the end of a card/line. The numbers in the stream are read in one at a time, when requested, from left to right. For example, if the number is a whole number (or integer) it may be read in by ININT, e.g. I:= ININT will read value of integer I from input data. If it is a real number it

may be read in by INREAL, e.g. X:= INREAL reads out value of real X from input data. Similarly, OUTINT is used to output an integer, e.g. OUTINT (I,5) prints out value of integer I within a field of 5 characters. OUTFIX is used to output a real variable, e.g. OUTFIX (expr,M,W) writes out value of 'expr' with M decimal places in a field of width W characters. OUTTEXT ("TABLE OF RAINFALL, YEAR 1960") prints the heading shown within double quotes and OUTCHAR ('*') prints the character *. They are enclosed within single quotes. The words INIMAGE and OUTIMAGE are used to skip to next line in the input and output respectively.

APPENDIX II

ROAD AND EQUIPAGE ATTRIBUTES

Source: Gynnerstedt, Gosta, et al., 'A Model for the Monte Carlo Simulation of Traffic Flow Along Two Lane Rural Roads,' Statens Vag-och trafikinstitut(VTI), Report No. 143, 1979.

1. The Road

The road block is represented in the programme as an object from the class ROADBLOCK. This object has the following attributes:

(i) Location and length

WK	coordinate of road block beginning
WL	road block length

(ii) Road geometry and traffic regulation attributes

ROADWIDTH	road width class
LANE	occurrence of auxiliary lane/lateral space
WI	slope
WVBL	block speed for median equipage
WQ	Q-value
PASS	code relating to overtaking restriction

(iii) References

MAX	occurrence and coordinates of sight distance maximum
SIGHTREF	reference to distance length function.

2. The Equipage

In the programme the equipage is represented as an object from the class VEH. The object has the following exogenous (EX) or endogenous (EN) attributes.

(i) Administrative attributes

ID	EX	identity number
DIRNU	EX	direction number
D1	EX	direction one
ORIGIN	EX	number of the road block for start of equipage
ARRIVALTIME	EX	arrival time
BLNU	EN	block number
DEST	EX	number of the road block for destination of equipage
FINISH	EN	destination reached

(ii) Driver-vehicle attributes

SPCLASS	EX	speed class
TIMEHEADWAY	EX	time headway
MINTIME	EX	shortest stay in auxiliary lane/ lateral space after passing
P	EX	power/weight coefficient allotted
TYPE	EX	vehicle type
AIRRESIS- TANCE	EX	air resistance coefficient
ROLLRESCOEF	EX	rolling resistance coefficient

(iii) Traffic attributes of the equipage

FOLLOWER	EN	equipage is following
BEHCATCHUP	EN	equipage is caught up
LOCALS	EN	road coordinate at preceding event
LOCALTIME	EN	time of preceding event
LOCALSP	EN	speed at preceding event
AVERSP	EN	speed from preceding event to next event
NEWPRE-TIME	EN	predicted time of next event
PREBL-TIME	EN	predicted time of passage of next road block border
PREBLSP	EN	predicted speed at passage of next road block border
FREEBLSP	EN	free block speed

(iv) References

BLOCK	EN	reference to actual road block
PSVEH	EX	reference to a 'pseudo equipage object' .